PB 189 266

EVALUATION OF PROCESS ALTERNATIVES TO IMPROVE CONTROL OF AIR POLLUTION FROM PRODUCTION OF COKE

Thomas M. Barnes, et al

Battelle Memorial Institute
Columbus, Ohio

31 January 1970

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PB189266

FINAL REPORT

on

EVALUATION OF PROCESS ALTERNATIVES TO IMPROVE CONTROL OF AIR POLLUTION FROM PRODUCTION OF COKE

(Contract No. PH 22-68-65)

to

DIVISION OF PROCESS CONTROL ENGINEERING

NATIONAL AIR POLLUTION CONTROL ADMINISTRATION

DEPARTMENT OF HEALTH, EDUCATION AND WELFARE

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January 31, 1970

BATTELLE MEMORIAL INSTITUTE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

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Department of Health, Education and Welfare

January 31, 1970

by

Thomas M. Barnes, Principal Investigator
Albert O. Hoffman, Principal Investigator
H. W. Lownie, Jr., Project Director

BATTELLE MEMORIAL INSTITUTE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

Battelle Memorial Institute · COLUMBUS LABORATORIES

505 KING AVENUE COLUMBUS, OHIO 43201 · AREA CODE 614, TELEPHONE 299-3151 · CABLE ADDRESS: BATMIN

January 31, 1970

Mr. Norman Plaks
Division of Process Control Engineering
National Air Pollution Control Administration
5710 Wooster Pike
Cincinnati, Ohio 45527

Dear Sir:

Final Report on
"Evaluation of Process Alternatives to
Improve Control of Air Pollution From Production of Coke"
(Contract No. PH 22-68-65)

One hundred copies of the subject report are submitted herewith.

This completes Battelle's assignments under the subject contract.

Very truly yours,

HWLownie Jr

H. W. Lownie, Jr.
Project Director

HWL/jbs
Enc. (100)

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SECTION I

SUMMARY

This Final Report presents findings and recommendations from a 6-month study of air-pollution control in the manufacture of blast-furnace coke. The study was performed by Battelle Memorial Institute, Columbus Laboratories, under the sponsorship of the National Air Pollution Control Administration (NAPCA), an agency of the United States Department of Health, Education and Welfare.

Battelle investigated two different paths to the alleviation of coke-plant emissions:

(1) The provision of new or improved equipment for control of emissions from conventional coke ovens

(2) The development of new, potentially cleaner processes for the conversion of coal into blast-furnace coke.

The objective of this study has been to identify and evaluate significant technical opportunites for improvement of air quality in and near coke plants. The investigators have examined current developments in both North America and Europe, with a view toward identifying promising concepts and considering them for trial or further development in the United States.

The findings are organized in this report in five sections:

I. SUMMARY
II. INTRODUCTION AND BACKGROUND
III. CONVENTIONAL COKING PROCESSES
IV. NEW COKING PROCESSES
V. EVALUATION AND RECOMMENDATIONS

Concepts of air-pollution control technology have been emphasized, but brief descriptive material regarding coking equipment and processes has been included (in Section II) to aid the nonspecialist reader. Information both general and detailed about the coking process and the overall theory of coal carbonization is available in standard texts.(1, 2)

The data and concepts discussed in this report were developed mainly by inquiry and personal interview among builders of coke plants and developers of new coking processes. A list of companies and other organizations that were contacted is given in Table I-1. Battelle gratefully acknowledges the generous participation of these sources (and numerous individuals) who contributed data, drawings, ideas, and opinions.

A group of steel industry air-quality experts, known as the Steel Industry Liaison Committee, was appointed by NAPCA to review this report in draft form. The efforts of

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(1) The Making, Shaping, and Treating of Steel, 8th Edition, United States Steel Corporation, Pittsburgh (1966).

(2) Supplementary Volume, Chemistry of Coal Utilization, John Wiley & Sons, New York (1963).

TABLE I-1. PRINCIPAL SOURCES OF INFORMATION ON THE CONTROL OF COKING EMISSIONS AND ON NEW COKING PROCESSES

United States

Koppers Company, Inc., Engineering and Construction Division
Allied Chemical Corporation, Process Plants Construction Division
AnDid Corporation
Tailor and Company, Inc.
Kennecott Copper Corporation, Peabody Coal Company Division
FMC Corporation, Chemical Divisions

Canada

The Steel Company of Canada, Ltd.
The Algoma Steel Corporation, Ltd.

Federal Republic of Germany

Didier-Werke AG.
Firma Carl Still
Dr. C. Otto & Company GmbH.
Heinrich Koppers GmbH.
Lurgi Gesellschaft für Chemie und Hüttenwesen mbH.
Steinkohlenbergbauverein, and Bergbauförschung (a Division)
Hartung und Kuhn, GmbH.
Werk Zollverein, Rhein-Elbe Coal Company

Belgium

Institut National de l'Industrie Extraitive (INIEX)

France

Carbonisation Entreprise et Ceramique S.A. (CEC)

United Kingdom

Simon-Carves, Ltd.
Woodall-Duckham, Ltd.
Gibbons Brothers, Ltd.

members of the Committee toward elimination of errors and omissions are acknowledged with thanks. However, their participation and assistance should not be construed as approval of or concurrence with the findings expressed in this report.

Conventional Coking

It is conceivable that the conventional slot-oven coke plants that account for nearly all U. S. blast-furnace coke may someday become obsolete. However, even the most ambitious proponents of newer coking processes recognize that any fundamental change in our coking methods must be evolutionary. It is likely that at least 20 years would elapse before any successful new coking process could entirely displace present coke ovens, and this evolution has not yet begun. Accordingly, for a reasonably prompt improvement in air quality around cokemaking operations, it is urgent to deal with emissions from the slot-oven coking process.

For slot-oven coking, the following seven primary sources of dust, smoke, and gas were given consideration:

(1) Handling, crushing, and blending of coals

(2) Charging of coal into the slot ovens

(3) Underfiring slot ovens with fuels containing sulfur

(4) Sealing of coke ovens during early stages of coking

(5) Discharging of newly produced coke

(6) Quenching of hot coke

(7) Handling and screening of coke.

Because of numerous similarities, coal handling and coke handling [Items (1) and (7)] were studied together. The scope of this study excluded the receipt and storage of coking coals, and also the processing of crude coking distillate gases to obtain by-products. The importance of individual items in the above list varies from plant to plant, but in well-run existing plants, the charging, discharging, and quenching [Items (2), (5), and (6)] seem to be the most serious sources of emissions in roughly the ratio 60:30:10.

It has been found, as one principal conclusion of this study, that air-emissions controls available (or becoming available) for slot-oven coke plants are characterized by three problem aspects:

- They are (or are likely to be) imperfect in controlling emissions, although they can contribute to significant lowering of air pollution.

- They are (and will be) costly to install and to operate; they generate few or no offsetting credits to the process.

- They are (and will be) sensitive, and will require serious attention to proper operation and maintenance; they will fail if ignored or overloaded.

The main point is that large investments in new equipment can make a contribution to air quality at and near coke ovens, but by their very nature such ovens will always be emissions sources to some degree. Furthermore, the desired technical conquest of coke-plant emissions requires continuing effort and contributions from both equipment engineers and plant operators.

Another principal conclusion, affecting all detailed findings, is that there are no generally (universally) accepted devices or procedures for measuring and evaluating emissions and emissions control for coke ovens. This is a serious handicap because it forces all concerned to take a qualitative, even judgmental, approach to a problem that is essentially quantitative.

These two conclusions lead directly to an overall primary recommendation regarding air-pollution control in slot-oven coke plants: It is urged that research instruments and procedures be aggressively developed for measurement of emissions from coke ovens. Such instruments and procedures are needed to permit quantitative evaluation of the effectiveness of control equipment and practices. It is important that such measurement devices and procedures be adaptable to study of both specific emissions sites and overall air quality near the ovens.

In the following paragraphs, some more specific findings and recommendations for slot-oven coke plants are presented topically. Arguments and explanatory detail for these findings and recommendations are presented in Section V.

Handling, Blending, and Crushing of Coals;
Handling and Screening of Coke

Dust raised during preparation of coking-coal blends may be contained adequately within local shrouds and within overall buildings of light construction. Where shrouding fails to contain dust, it is possible to provide drafted exhausting of dust through conventional dust-control equipment such as wet scrubbers. Most coal-handling facilities in the United States are at least partially shrouded and enclosed. Because most coking coals are processed in moist condition, emissions arise mainly from the accumulation, drying, and subsequent windblown release of coal dust that has escaped the system.

Attention should be given to upgrading present shrouding and enclosures to attain total weatherproof enclosure of coal-blending and coal-crushing facilities, from the point of entry into the preparation system to the point of discharge into a larry car or other charging device. At the points of entry and final discharge, as at internal points where shrouding is incompletely effective, the use of drafted systems for collection of dust is suggested. Dust entrained in the collector system should be removed by kinetic, wetting, or filtration methods, and exhaust should be monitored so that malfunctions in the dust system will shut down the plant. In addition, vacuum-cleaning devices (now provided for some new coal-handling systems) should be installed to facilitate effective housekeeping. Where access doors or windows are required, they should be self-closing. Because coal dust raised in enclosed space is a potential health and fire hazard, interlocks should be provided so that (1) the dust-collecting system will operate for at least several minutes after disruption or shutdown of the main plant and (2) the plant will stop immediately upon failure of draft (not necessarily power) in any part of the dust-collecting system.

Most aspects of coke handling are more or less analogous to the dust problems of coal handling, save that coke is usually drier. Much of the dust raised in coke handling occurs at the screens which separate fine breeze and intermediate sizes (such as nut coke) from the larger sizes used in the blast furnace. Generally, the approach to alleviation of coke-handling dust should be the same as for coal handling, and should be based upon weatherproof buildings, shrouds, dust-collection devices, and modern housekeeping equipment.

A special problem, however, arises from the practice of accumulating nut and breeze coke in open hopper cars underneath or adjacent to the screening station. The loading of these cars is not readily enclosed or provided with drafted dust collection. For each plant, specialized solutions must be engineered (actually tailored) to existing configurations of chutes and trackage. There is opportunity for innovations such as rewetting of breeze or the use of condensing steam to blanket the escape of dust.

Charging of Coal Into the Slot Ovens

Two conceptually different approaches to the control of charging dust and smoke are in active development, both in the United States and in Europe. One approach is based upon the concept that charging emissions should be drawn off, burned, and then exhausted through wet scrubbers; the emissions are drawn off through shrouds arranged around the charging ports. There are several variants of this idea, differing mainly in provisions for ignition of the gases, for the regulation of combustion air, and for scrubbing of the resulting gas/dust stream. The efficacy of this collection, ignition, and scrubbing approach has been questioned for United States conditions, but our newest plants are equipped with this type of apparatus.

The second approach is based upon the concept that the charging port or ports should be connected directly to the coal-conveying equipment and at least mechanically sealed, such that all smoke and entrained dust must be drawn into the standpipe that leads to the raw-gas collector main and thence into the by-product system. Two important variants of this approach must be considered:*

(1) One variant uses a specially equipped larry car, which temporarily seals its discharge pipes (mechanically) to the charging ports. Negative draft is maintained during all operations so that imperfect sealing will not lead to leakage of gas and smoke.

(2) The other variant dispenses with the larry car and the usual charging ports. This system is replaced by a manifolded, permanently connected, pneumatic (but airless) charging system which blows the coal through a single horizontal port at one end of the oven.

The overall efficacy of this second approach has been questioned on the possibility that the by-product system may become fouled with an accumulation of dust.

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*There are other variants, discussed in Section III, but these are not yet actively developed.

At the time of this writing, neither of the two principal approaches has become a standard practice in North America, but new coke-oven batteries are being equipped with wet-scrubbing systems.

In Battelle's judgment, neither the first approach (collection and scrubbing) nor the second (exhausting via the by-products system) now stands proved or disproved for use in the United States. Strong advantages and defects may be cited for both approaches in all of their embodiments, and different approaches may be preferred for different baseline conditions. It is recommended, therefore, that each of these approaches (actually three systems) be diligently developed and demonstrated to the point where, given measurement techniques and emissions targets, it will become possible to choose rationally among them.

The factors of choice include effectiveness, reliability, operating practicality, and cost; these factors need to be assessed in nose-to-nose confrontation at industrial scale. A clear and balanced choice, reflecting all of the above factors, is vital because it will maximize the potential for acceptance by industry, thus hastening installation of the chosen system or systems. Because air pollution from charging smoke is regarded as one of the most serious problems in both magnitude and importance, every encouragement to facilitate application and in-service evaluation of charging-smoke controls should be given.

Battelle ranks full-scale trial of systems for the control of charging smoke as equal in priority to the development of methods of measuring performance. There is hope that given appropriate support and encouragement all three principal systems could be operative at full scale on a demonstration basis within the United States by the end of 1971.

Because know-how, immediacy, and steel-industry acceptance are factors important to prompt widespread implementation of any system for controlling charging smoke, Battelle sees a major practical advantage to encouragement and support of the AISI plan to install commercial-scale equipment to demonstrate the capabilities of a system resulting from recent AISI research.

Underfiring Slot Ovens With Fuels Containing Sulfur

Underfiring is the name given to the regenerative combustion mechanism by which coke ovens are heated. Because uniformity and control of heating are important from operational and product standpoints, underfiring controls are sophisticated and combustion is carefully monitored. However, about 70 percent of all underfiring energy is derived from the burning of coke-oven gas.* Coke-oven gas, unless specially processed, may typically contain from 3.5 to 4.5 grains of hydrogen sulfide (H_2S) per standard cubic foot. This is the equivalent, on an energy basis, of a coal containing from 1.2 to 1.6 percent sulfur. When the coke-oven gas is burned, the H_2S is oxidized to SO_2 in the waste gases that are vented to the atmosphere. To the extent that combustion of coals in the range of 1.2 to 1.6 percent sulfur is considered to be an air-pollution problem, the underfiring operation must also be regarded as a source of SO_2 emissions.

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*Derived from AISI statistics showing use of 231,922 million cubic feet of coke-oven gas in underfiring 81.245 million tons of coal in 1968. This reduces to 710 Btu from coke-oven gas per pound of coal; total underfiring energy is about 1000 to 1100 Btu per pound of coal.

The appropriate place to strip hydrogen sulfide from coke-oven gas is within the by-products processing system, so that all of the gas is cleaned. No detailed study and assessment of stripping methods was performed, but some of the main techniques are described in Section III of this report. Stripping and disposal of hydrogen sulfide is relatively costly by present methods, and it is appropriate to recommend expansion of present development efforts in this field. According to some accounts, the cost of stripping hydrogen sulfide (at about 75 percent effectiveness) can easily exceed the fair value of the coke-oven gas as a fuel. This situation notwithstanding, the formation of the gas accompanies coking, and it cannot be "made to disappear" simply because it becomes valueless.

Sealing of Coke Ovens During Early Stages of Coking

Ordinary charging-port lids, if kept reasonably clean, will usually close adequately (at least after the coal is leveled) because the free space above the coal is at low pressure relative to the sealing forces, and because the small mating surfaces can be designed to fit well. The self-sealing doors at each end of an oven, however, are subjected to higher relative pressures and to more distortion of much larger mating surfaces. In all but exceptional plants, doors typically leak for an hour or more, the amount of leakage varying inversely with the amount of maintenance attention given to the seals. The self-sealing principle commonly used butts the edge of a narrow steel strip against a flat surface; it is not a true seal. In fact, self-sealing doors depend upon eventual blockage of the usual hairline crack by condensation of tars from leaking tar vapor.

Door sealing is inordinately sensitive to operating attitudes. The relatively clean operation of a battery of 80 ovens, 19-1/2 feet high, on a 16-hour coking cycle, requires the meticulous cleaning and adjustment of roughly 2 miles of seals and mating jambs every day. If cleaning is allowed to lapse, it becomes more difficult on subsequent cycles. Operators of the new tall ovens report that hand cleaning or even hand touch-up of mechanically cleaned seals on 20-foot doors is impractical, and that existing door-cleaning machines cannot be relied upon to do a complete job every time.

The replacement of present types of metal-to-metal door seals with "true" seals appears to be unfeasible. True seals must be based upon either soft gaskets (such as asbestos or elastomers) which can foul or become damaged, or upon luting (caulking) of the seal area with clay or other soft filler, which is a hand operation. Also, the hooding of end doors and connection of the hoods to an exhaust and scrubber appears to be neither effective nor practical.

There exists a German system whereby end-door seal areas are back-pressurized (from the inside) with coke-oven gas such that tarry vapors are flushed away before they can form deposits. Modest pressures and modest amounts of gas are involved, and most of the pressurization gas is recycled into the by-product system. A fraction of the gas breaks down and deposits fluff carbon, aiding the metal-to-metal seal, but at the end of a coking cycle, this fluff carbon is easily knocked off by a mechanical door cleaner. On the grounds that alleviation of the door-cleaning problem will lead to better seal maintenance, it is recommended that this system be installed on a demonstration basis in the United States. The original German design provides for quick-disconnect gas connections through the doors themselves; this is unwieldy. A British variant introduces the back-pressurizing gas through the door frames, and this approach appears to be quite practical from an operating viewpoint.

Discharging of Newly Produced Coke

Both dust and smoke are released at the time coke is pushed from the slot oven. Of these, the smoke is the more serious air pollutant. All known approaches to the mechanical containment and/or collection of these pushing emissions appear to be very costly and far from effective. Some suggested systems could not be applied to existing coke-oven plants because of space or elevation problems. Above these considerations, it appears that none of the suggested systems can hope to deal with a "green" push – one in which there is much incompletely coked coal owing to heating defects or other deviations from normal practice.

Developments in three European systems of hardware for direct control of coke-pushing emissions should be watched closely. The three systems now considered important are those of Hartung und Kuhn (hood), Heinrich Koppers (traveling quencher based on rotary drum), and Carl Still (closed hot-coke receiver plus continuous grate for quenching). Coming trials of these systems (some already in progress) should lead to clear criteria for a U. S. pushing system or a combined pushing and quenching system. Some of the combination ideas that should be explored include quenching on an endless (or circular) grate, dry quenching combined with use of warm coke in the blast furnace, and flooding of the coke as it is pushed so that little or no steam is raised.

At the same time, it appears that there are appropriate areas for research toward the direct alleviation of pushing emissions. One promising line of inquiry would be to study, in at least three and preferably five coke plants, the relationship between green coke and the following variables of practice:

Coal volatile matter

Coal bulk density

Original coal moisture

Oven fill level (as related to flue design)

Coking time

Rate of heating

Temperature gradients.

From research of this type, it should become possible to specify useful methods for determining the amount of smoke as a function of coking time for a given battery, coal, and practice. This research could not be done by formula; experimental work would be required. Despite the present lack of instruments suited to the direct measurement of pushing smoke, the greenness of coke could be estimated via measurements of the rate of raw-gas evolution just prior to pushing. Whereas it would not be reasonable to plan toward statutory regulation of heating practices or coking times, it is feasible to encourage the operation of coke ovens in accord with equitable guidelines that will limit the amount of pushing smoke in most instances.

Quenching of Hot Coke

The installation of opposed courses (usually two courses) of louver baffles across the interior of a quench tower curtails the emission of grit significantly. The degree of alleviation apparently depends upon the amount of care and money expended upon engineering and installation of the baffle system.

Some experimental studies of various baffle arrangements have been performed, but most of these have been before-and-after proof tests on a limited number of baffle arrangements. Also, much of this work has measured (1) near-range fallout only or (2) total emissions only. More experimental work is recommended, in part because the high effectiveness of simple designs suggests that full and final solutions are within reach. Future experiments should be based upon study of several designs of towers, should cover a number of baffle configurations, and should include measurement of both total emissions and near-range fallout.

Until recently, a few U. S. coke-quenching operations have been used as disposal plants for water contaminated by ammonia, phenols, and other potential air pollutants. Even where clean water is used for quenching makeup, it is possible that this water might become contaminated by repeated use. It is recommended that the use of contaminated water for quench makeup should cease, and that experiments should be performed to determine whether there is need to take additional precautions.

Overview on Conventional Coking

For advancing the technology of emissions control in slot-oven coking, further efforts of government, steelmakers, and plant builders should be correlated so as to complement and reinforce one another. Battelle recommends the following:

Highest Priority:

- Development of methods and devices for measurement of (1) overall achievement and (2) performance of individual controls.
- Full-scale installation, trial, and comparison of three prominent systems being developed for control of charging smoke.

Desirable Demonstration Project:

- Installation of a system for back-pressurizing coke-oven seals from inside with coke-oven gas.

Applied Experimental Research:

- Determination of relationships governing evolution of smoke at the time an oven is pushed.
- Comparative evaluation of several quench-tower and grit baffle designs.
- Study of the accumulation and release of vaporizable compounds in quench water.

Conceptual Study:

- Evaluation of the effectiveness and cost of systems for removal and conversion of hydrogen sulfide in coke-oven gas.

Other projects, which may grow in importance as progress is made (or not made), are outlined in Section V of this report. An annual review of progress and priorities is recommended.

New Coking Processes

For many years, steel companies, coke-plant builders, and other related interests (such as operators of submerged-arc electric smelting furnaces) have been seeking new methods for making coke. Air-pollution problems and environmental health hazards associated with conventional coking have provided some of the incentive, but the main motivation has been to utilize noncoking coals. The conventional slot-oven coking process still dominates because there is no proven substitute in terms of

(1) Product suitability for the blast furnace

(2) Overall process economics.

However, new coking processes are being actively developed, the associated entrepreneurs are gaining confidence, and the steel companies and coke-plant builders are watching closely. Some observers believe that a new coking process (for blast-furnace coke) could become a commercial reality within 5 years; other observers think that the required development would take longer.

This study of air pollution from coking has included examination of several unconventional coking processes that are in the pilot-plant and demonstration or commercial stages. It is concluded that each of these processes appears more amenable than slot-oven coking to the control of air-polluting emissions. It is certain that the level of emissions from conventional ovens can be lowered significantly only at an increase in cost of coke. It is believed that the minimum attainable level of emissions from slot-oven coking will not be so low as the level of emissions to be expected from well-engineered continuous coking. Although continuous coking processes also generate gas, smoke, and dust, the design of the plants can be such that these materials can be channelled to stationary collectors and processing systems.

Present deterrents (questions of economics and product suitability) to the development and commercialization of new coking processes are compounded by (1) limited knowledge of the properties essential to a good blast-furnace coke, (2) the large cost and substantial risk involved in the manufacture and use of continuous-process coke for blast-furnace demonstrations, and (3) incomplete information about the comparative costs of new versus conventional coking processes operated with maximum control of emissions. Comparative costs now considered unfavorable to continuous coking may be reversed if emissions-control costs are added to conventional-coking costs.

Because continuous coking processes do have distinct potential for lowering the total level of coking emissions, continued development and industrial trial of these processes should be encouraged. One important contribution would be research conducted to improve understanding of coke properties affecting performance in a blast furnace. Wherever and whenever a new coking process attains sufficient promise to be considered for full-scale trials of the product, it is recommended that the demonstration plants should be engineered and equipped for demonstration of emissions control as well as process and product capabilities. Because some coal-gasification and coal-liquefaction processes yield, as a by-product, char that might be suitable for the manufacture of formcoke, linking of a coal-chemicals plant and a formcoke plant should be investigated in more depth from a conceptual point of view.

Overview on New Coking Processes

For advancing the technology of new continuous coking processes potentially capable of good control of emissions, further efforts of government, steelmakers, process proponents, and plant builders should be correlated so as to complement and reinforce each other. Battelle recommends the following:

Highest Priority:

- Further development of new, continuous coking processes, with emphasis on their ability to contain and control emissions.

Applied Experimental Research:

- Research to develop laboratory tests suitable for predicting how a new coke will perform in a blast furnace, and for predicting the conditions of blast-furnace practice that will optimize the performance of new types of coke.

Conceptual Study:

- Technical and economic appraisal of the possible favorable relationships between combined formcoke processes and chemical coal-processing projects.

Importance of Time

The conventional batch slot-oven coking process has been judged as a result of this study to be poorly suited for positive reliable control of air-polluting emissions to low levels. However, developments in progress are expected to lower emissions substantially from their present levels. Whether the improvements are adequate or not depends on standards to be set, and on the means to be used in obtaining compliance with the standards.

Methods for manufacture of blast-furnace coke by continuous processing in closed circuits offer a potential for control of emissions to very low levels. Thus, depending upon the nature of future standards, plants of the continuous type may provide the best avenue toward a final solution. However, the new processes have not yet been proved adequate in terms of coke quality and attainable productivity.

Considering the present status of continuous coking processes, it is unlikely that a commercial plant utilizing such a process will be operational to make blast-furnace coke prior to 1975. If and when the first continuous coking plants are built, their operations and products will be carefully evaluated by coke users before additional major commitments are made. This evaluation may be expected to occupy an additional 5 years, perhaps to 1980. Thus, even if all goes well, construction of continuous coking plants replacing conventional coke ovens is not likely to begin on a general basis for 10 years (say not before 1980). After this, it is likely that an additional 5 to 10 years (say to 1985 or 1990) will elapse before any substantial proportion of U. S. blast-furnace coke is made by continuous methods.

The foregoing expectations lead to the conclusion that if dependence is placed solely on new continuous processes for alleviation of air pollution attributable to coke production, and if such processes succeed in every way, the resultant decrease in overall emissions could not become significant for about 15 or 20 years at best. Accordingly, in the shorter range, attention must be focused on the lowering of emissions from conventional coke ovens. It is only by diligent improvement of existing plants that we can hope to

(1) Produce immediate benefits for the public

(2) Determine the final limitations applying to present processes

(3) Keep the economic confrontation between old and new coking methods in appropriate balance.

SECTION II

INTRODUCTION AND BACKGROUND

This Final Report presents findings and recommendations from a 6-month supplemental study of the alleviation of air pollution from the coking process. The study was performed by Battelle Memorial Institute, Columbus Laboratories, under contract to the National Air Pollution Control Administration. The work represented by this report (one of three issued so far on steel-industry topics)(1) was authorized June 20, 1969, by Modification 7 to Contract No. PH 22-68-65, entitled "Systems Analysis Study of the Integrated Iron and Steel Industry".

Origin of the Project

The Air Quality Act of 1967, enacted by Congress as Public Law 90-148, confers responsibility for federal efforts to lessen air pollution upon the Secretary of Health, Education and Welfare. The assigned obligations include:

> "Research . . . and studies relating to the causes, effects, extent, prevention, and control of air pollution (Sect. 103a)
>
> "A comprehensive study of the economic impact of air quality standards on the Nation's industries . . . (Sect. 305a)."

In discharging these and other obligations, the Secretary has created a specialized agency, the National Air Pollution Control Administration (NAPCA). NAPCA is a part of HEW's Consumer Protection and Environmental Health Service. A part of NAPCA's work is to conduct technical and economic studies to define the problems, achievements, and probable costs of air-pollution control in certain American industries. In addition to the steel industry, NAPCA is studying industries concerned with nonferrous metals, iron foundries, electric energy, chemicals, and pulp and paper. A particular object of industry studies is to identify situations where there is need for programs of intensive technical research and development. A second major object is to determine the probable present and future expenses likely to be incurred by each industry as firm air-pollution control standards evolve.

An analysis of air-pollution problems, technology, and control costs in the American iron and steel industry was undertaken by Battelle for NAPCA in June, 1968. At the same time, a Steel Industry Liaison Committee representing 11 steelmaking companies was appointed by NAPCA. The Committee assisted with the assembly of data, and also advised and reviewed the efforts of Battelle and of Swindell-Dressler Company, Battelle's subcontractor. The original research contract defined nine specific study tasks, and results of these tasks were reported in May, 1969. The present work, identified as Task 10, was undertaken because of the need shown by the initial studies.

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(1) Prior reports on air-pollution and its control in steelmaking are entitled "Final Technological Report on a Systems Analysis of the Integrated Iron and Steel Industry", and "A Cost Analysis of Air-Pollution Controls in the Integrated Iron and Steel Industry", both dated May 15, 1969. They are available from the Federal Clearing House for Scientific Information for $3.00 each as Numbers PB 184577 and PB 184576, respectively.

Origin of Task 10

Battelle's Final Technological Report dated May 15, 1969,(1) identified air pollution from the operation of coke ovens as a problem of highest priority. The emphasis upon coking as a problem arose from (1) the severity of coke-plant emissions (in both quantity and effect) and (2) the dearth of truly practical approaches to the alleviation of those emissions. Section II of the Final Technological Report said in part:

> "The manufacture of metallurgical coke is conducted in batteries of slot-type by-product ovens. The nature of these ovens is such that they give rise to air pollution. The research done since June, 1968, on Contract PH 22-68-65 has identified coke plants as probably the largest source of uncontrolled emissions to the air by the American steel industry. Because of the shortage of accurate and reliable data and measurements on emissions from coke plants, it is not possible at this time to prove the foregoing statement quantitatively, but knowledgeable persons in the steel industry and affiliated with it almost completely agree . . . (with this estimate). When the Industry Liaison Committee was asked to identify air-pollution problems deserving of further study by NAPCA, every respondent mentioned some aspect of coke-plant operation."

Section II of the Final Technological Report continued with an outline of recommended coking studies. The outline subsequently was modified by NAPCA's Division of Process Control Engineering to define Task 10, the subject of this Final Report.

Scope and Objectives of Task 10

Studies undertaken by Battelle in Task 10, and reported here, were defined by NAPCA in three major categories:

I. Assembly of new information indicating progress in the development of methods and devices for the control and alleviation of air pollution from conventional coke ovens

II. Assembly of new information indicating progress in the development of new coking processes of unconventional type, amenable to the production of blast-furnace coke and also to the improved control (or elimination) of air pollution

III. Determination of feasible process changes, equipment additions, or new processes that show clear-cut potential for alleviation of air pollution, and recommendation of research, development, and/or demonstration programs as required to implement promising techniques.

The above categories were selected by NAPCA for further study because they apparently define the opportunities for future supply of iron-smelting carbon within anticipated air-quality standards. Up to the present time, coke-plant emissions surveys and abatement activities have been handicapped by limited emissions information and by a lack of effective approaches to air-pollution control. For example, in March, 1969, NAPCA came to these conclusions about coking in the Ashland/Ironton area along the Ohio River:

> "1. Coke manufacturing contributes a significant amount of particulate pollution to the atmosphere of the area. This is true not only because of the copious quantity of the emission but because most of the discharges are at low elevations and in the urban area near residences.
>
> 2. Current control technology for coke ovens is not sufficiently developed to meet recommended process weight limitations, but available techniques can achieve significant reduction in emissions.
>
> 3. There are prospects for improved control technology. Most coking plant emissions occur during oven-charging operations. The Allied Chemical Company has under active development at its Ironton Plant a method ... (described). Successful application of this method will virtually eliminate emissions during charging."

The recommendation of the Federal Abatement Conference(2) was:

> "As soon as practicable and no later than July 1, 1970, coke manufacturing operations in the area (shall) reduce particulate process emissions to the lowest practicable level by the application of the best available control technology."

In the above specific case, NAPCA was unable to state precisely what kinds of air-pollution controls should be applied. The one specific reference (to Allied's new charging system) is hopeful rather than assured. Environmental-control authorities, as of now, are unable to specify ways to abate coke-plant air pollution to any adequate degree.

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(2) Recommendations and Summary of Federal Abatement Conference on Interstate Air Pollution; Ironton, Ohio - Ashland, Kentucky - Huntington, West Virginia, March 14, 1969.

In dealing with coke-plant air pollution, both NAPCA and the coke producers need to know much more about the alternatives for emissions control, about the factors affecting selection among these alternatives, and about the operating implications of each approach. It is certain that full development of adequate air-pollution controls for coke plants is going to require several years of innovation, trial, and improvement. Whereas NAPCA is in a position to aid and abet this process with both guidance and assistance, the effective management of either industrial or public efforts in this area will need (1) establishment of an effective technical dialogue, (2) a realistic assessment of prospects and problems, and (3) a unified investigation and evaluation of existing proposals. The addition of Task 10 to the steel-industry studies has been intended as a start toward satisfaction of the above needs.

The viewpoints of coke producers, coke-oven builders, promoters of novel coking methods, and air-pollution control authorities frequently will differ. It is doubtful whether any comprehensive study and report of this kind could ever be distinguished by the term "consensus". In conducting Task 10, Battelle sought the opinions and viewpoints of many interested parties, reported them, and evaluated them. This report is organized to present the situation as conveyed to Battelle in Sections III and IV, with Battelle's own appraisal and interpretation reserved to Section V. Although many of Battelle's judgments are clearly arguable, the questions raised by a study of this kind are not capable of being settled by debate alone. For this reason, Battelle recommends to NAPCA a series of investigations, experiments, and demonstrations that would point toward some of the answers. It is hoped that a consensus can be reached on the merits of this suggested program.

Methodology

The analyses and descriptions that make up the body of this report are based upon inquiry directed to the manufacturers, proponents, and users of equipment and processes for the manufacture of blast-furnace coke, generally excluding steelmakers within the United States. (American steelmakers were interviewed on this subject during the prior part of this general investigation.) Preparatory to each principal inquiry visit, Battelle made informal contact followed by formal contact (a letter) explaining this project and the specific inquiry. Each letter enclosed a statement of project objectives (Appendix A) and requested a written response. NAPCA reviewed the responses and approved the visits on an individual basis. Table II-1 lists the visits made during the course of the inquiry phase of this project. Certain European contacts, as noted in Table II-1, were visited as "targets of opportunity" without a prior exchange of letters.

During visits to the offices and plants of source companies, the inquiry team used informal interview methods only. The informal approach served in most instances to defocus preconceptions of the inquiry team's status as "air-pollution investigators". Conversations included discussion of each company's business relationships with the coking industry and with related companies in other countries, and also touched on coking technology in general. The informal line of inquiry among coke-oven builders, phrased generally as given below, emphasized present and prospective controls for alleviating air pollution:

TABLE II-1. INQUIRY VISITS MADE TO DOMESTIC AND FOREIGN SOURCES OF INFORMATION

Date (1969)	Company or Agency (Type of Facility)	Location	Persons
Aug. 20	FMC Corporation (pilot plant)	Philadelphia, Pa.	Mr. Erik Saller
Aug. 22	FMC Corporation (demonstration plant)	Kemmerer, Wyo.	Mr. Allan Ackers Mr. Wendell Darrow
Aug. 26	AnDid Corporation (sales offices)	Pittsburgh, Pa.	Mr. Conrad Waibel
Aug. 26	United States Bureau of Mines (laboratories)	Pittsburgh, Pa.	Mr. David Wolfson
Sept. 5	Peabody Coal Company (demonstration plant)	Columbia, Tenn.	Mr. Vaughn Mansfield
Sept. 11	Koppers Company (engineering offices)	Pittsburgh, Pa.	Mr. Edward Helm Dr. Terence Dancy[a]
Sept. 12	Allied Chemical Corporation (offices)	New York, N. Y.	Mr. George Balch Mr. H. S. Auvil
Sept. 22	Allied Chemical Corporation (offices)	Morristown, N. J.	Mr. W. E. Luley Mr. Bob Zunkley
Sept. 29	The Steel Company of Canada, Ltd. (plant)	Hamilton, Ont.	Mr. J. S. Anslow
Sept. 30	The Algoma Steel Corporation, Ltd. (plant)	Sault Ste. Marie, Ont.	Dr. J. A. Standidge
Oct. 6	Firma Carl Still (engineering offices)	Recklinghausen, W. Germany	Mr. Weiss Mr. Stratmann
Oct. 6	Dr. C. Otto & Company GmbH. (engineering offices)	Bochum, W. Germany	Dr. Schoen
Oct. 7	Heinrich Koppers GmbH. (engineering offices)	Essen, W. Germany	Dr. Johannes Franzen Mr. Walter Cremer
Oct. 8	Lurgi Gesellschaft für Chemie and Hüttenwesen mbH. (engineering offices)	Frankfurt, W. Germany	Dr. Roland Rammler Dr. Paul Schmalfeld
Oct. 9	Hartung and Kuhn, GmbH.* (offices)	Düsseldorf, W. Germany	Mr. Kurt Asmus Mr. H. Heinbresse
Oct. 9	Rhein-Elbe Coal Company* (coke plant) (also known as Zollverein)	Essen, W. Germany	Mr. Hörter
Oct. 10	Steinkohlenbergbauverein, and Bergbauforschung* (a division) (offices and pilot plant)	Essen, W. Germany	Dr. Kurt-Gunther Beck Dr. W. Eisenhut Dr. Edwin Ahland
Oct. 10	Didier-Werke AG. (engineering offices)	Essen, W. Germany	Mr. Hans-Herman Müller
Oct. 13	Institut National de l' Industrie Extraitive (pilot and demonstration plants)	Liege, Belgium	Dr. P. Ledent Mr. Burton
Oct. 14	Firma Carl Still, and Eriniat Castrop-Rauxel (engineering offices; coke plant)	Recklinghausen, W. Germany	Mr. Weiss Mr. Stratmann Mr. Bruns
Oct. 14.	Woodall-Duckham, Ltd. (engineering offices)	Crawley, U. K.	Mr. J. Maloy
Oct. 15	Simon-Carves, Ltd. (engineering offices)	Stockport, U. K.	Mr. A. D. Murphy Mr. R. H. Chambers
Oct. 17	Gibbons Brothers, Ltd. (engineering offices)	Brierly Hill, U. K.	Mr. D. A. E. Evans Mr. Tweddle
Oct. 17	Carbonisation Entreprise et Ceramique SA. (offices)	Paris, France	Mr. Rene Fumey

*Target of opportunity; visited without exchange of formalities.

(a) Dr. Dancy is employed by J & L Steel, and is Project Manager for the AISI program of charging-smoke controls development.

(1) What is your working approach to the development of controls for alleviation of air pollution from the coking process?

(2) Which problems do you consider solved in terms of changes you can make in existing ovens?

(3) What new designs have you adopted as standard equipment to improve the cleanliness of ovens now being built?

(4) What kinds of optional air-pollution control equipment have you engineered and installed for your customers?

(5) Do you regard the larry car as a permanent fixture, or are you trying to replace it with a different approach to charging?

(6) What are the prospects for direct hooding and cleaning of smoke and grit produced during the pushing of coke?

(7) What is your opinion of alternatives to conventional coking?

(8) What is your opinion of the total enclosure of coke ovens?

For oven builders, the overall goal was to learn what they are supplying and what they hope to supply in the future for emissions control.

Battelle sought answers along different lines of inquiry from proponents of unconventional coking processes. An object was to determine process feasibility as well as potential for air-pollution control:

(1) How does your process work? What are its unique features?

(2) What are the characteristics of the coke produced?

(3) What are the indications that this coke would be usable in blast furnaces?

(4) What is your impression of the status of formcokes generally?

(5) What is the next step toward gaining acceptance and use of your process (or product) by steelmakers?

(6) In what ways is your process specially suited for containment and collection of potential air pollutants?

The overall goal was to put each new coking process into a frame of reference illustrative of its standing and its potential.

Section III of this report presents the results of inquiries about conventional slot-retort coking, and Section IV gives information obtained about new coking methods.

The analysis phase of this project regrouped the information in topical alignment, presenting and comparing all ideas received on each aspect of the problem. Consideration of the data as thus regrouped led to the conclusions and recommendations expressed in Section V.

In many instances, air-pollution control concepts or new approaches to coking were judged for their conceptual feasibility. These judgments were formed in terms of practical questions, such as:

(1) Will the proposed innovation produce an appropriate improvement in air quality?

(2) To what extent is the innovation sensitive to operating or maintenance attitudes and skills?

(3) Will the innovation produce any unwanted effects upon productivity or coke quality?

(4) Has the innovation's probable cost been assessed, and if so has the innovation been judged worthy for application of venture capital?

(5) What will happen to coke production under conceivable conditions of process or device failure? What will happen to emissions?

(6) How real is this idea? Has it been used at commercial scale?

(7) How does this innovation differ from or improve upon other conceptually similar approaches?

(8) To what extent does this approach exchange air pollution for water pollution or other environmental disruption?

(9) What is needed to bring this innovation to bear upon U.S. problems? How long is the apparent development road?

Independent estimates of cost as related to control effectiveness were not made by Battelle in any quantitative sense during this project. In general, judgment as to feasibility with respect to cost and effectiveness was influenced by consideration of the amount and source of venture capital brought to bear upon each innovation. In most instances, lowest rank was assigned to pure concepts not in active development, and highest rank was assigned to commercial apparatus for sale and being sold. Between these extremes, among projects in various stages of development of demonstration, some consideration was given to sources of financial support. Concepts being underwritten by steelmakers, coke-oven builders, and other private enterprise were rated higher than concepts financed by state or federal government agencies. Although this approach to ranking has flaws, it is appropriate when hard cost data cannot be obtained.

An Introduction to Coke and Coking

For the present purposes, coke is defined as a solid form of carbon resulting from the destructive thermal distillation of coal. Analogous materials include wood or bone charcoal and petroleum coke (the final residue from refining of crude oil). Nearly all coke is produced by progressively heating pulverized coal (usually a blend of several types) to high temperature over a period of 10 to 40 hours. The types and properties of coke produced are determined by the heating cycle, the coals used, and the configuration of the heating system.

Coal is not a crystalline material like the rock strata in which it is found. Instead, most components of coal are highly complex solid organic molecules, related to the aromatic family of hydrocarbons based upon the benzene ring. The molecules consist of chains or platelets of these rings. Familiar compounds in this family include benzene, naphthalene (moth crystals), and anthracene (the main component of tar). When coal is heated, many of these compounds liquefy. As temperatures continue to rise above roughly 500 to 700 F, some of the organic compounds begin to vaporize; others begin to break down chemically. For the manufacture of blast-furnace coke, temperatures are carried to well above 2000 F, and less than 2 percent of volatile matter (as measured by weight loss during high-temperature firing) remains in the coke.

The essence of coking success, whether by slot-retort ovens or other means, is to manage the evolution of vapors and the breakdown of organic matter so that a strong residue of coke is formed. The coke itself is the object of coking, and its essential characteristic is physical durability at both handling and operating temperatures. In slot-retort ovens, the coal charge is physically contained by the sides, bottom, and ends of the retort, and by its own weight from above. As the coaly matter breaks down, assuming proper coal blending and appropriate heating rates, the gases and vapors escape without building to damaging pressures, yet the formation of the residue coke is constricted so that a dense product results. Even the bulk density of the wet coal charge is carefully managed, with oiling of the coal if necessary, so that the coke will be dense enough for strength but will not generate damaging wall pressures. If there were no retort, a light, thin-walled, weak coke could be produced by free expansion of bubbles in an unrestrained liquid phase; if the retort were packed tight, it would be destroyed by inordinate internal pressures.

In formcoking, which is a continuous or semicontinuous process, the same cycle of coal liquefaction and outgassing must be managed without a retort. Often, this means that some or all of the coal must be converted to char (taken through all or most of the thermal cycle) before the briquettes or other agglomerates are formed. For example, a pillow-shaped briquette may be made from coal char bonded with pitch, or from char briquetted together with uncharred coal that has been heated to its fluid state. Subsequently, shock heating or other managed heat transfer is employed to cure and coke the binder phase so that it will (1) give off its gases and vapors without overstressing and breaking the briquette, and (2) heat quickly enough that the agglomerate will not slump by oversoftening of the binder phase. Formcoking processes are meticulously tailored to the properties of the coals used. In contrast, conventional slot-retort coking requires careful tailoring of coals and practices to the process.

Section III of this report will deal with the control of air pollution from conventional coking practices, which are also called "slot-oven coking" or "by-product coking". All of these modifiers are descriptive. The process is "conventional" because it accounts for 98 percent of total United States coke production. It is performed in slots constructed of complex silica brickwork, arranged like books on a shelf for efficient heating via flues in the interwalls. The typical dimensions of a single slot are 12 to 22 feet high, 40 to 55 feet long, and 14 to 20 inches wide. These slots are true chemical retorts, in that they are batch-operated, fitted with exhaust flues (called standpipes), and function without any addition of reagents once the charge is placed. The reference to by-products arises from the usual practice of collecting and thoroughly processing the vapors and gases evolved during coking. The chemicals and fuels thus derived (principally tar, light aromatic oils, and a 550 Btu/cu ft fuel gas) have traditionally offset direct coke-plant operating costs in full, although the prices for coking by-products have been under strong pressure from petroleum-based fuels and chemicals recently.

In operation, a coke oven is almost never deliberately cooled, because the siliceous brickwork will spall (or worse) if brought through its recrystallization temperature rapidly.* Once heated, a battery of coke ovens is kept working until it has deteriorated to the point of obligatory replacement some 20 to 40 years later. Coal is charged to each oven in rotation, and finished coke is pushed some hours later in the same rotation.

Coking begins with the preparation and blending of coals. Stocked coals, usually including at least one high-volatile, easily liquefied coal and one low-volatile, less-reactive coal, are comminuted in hammermills and carefully combined in preset proportions. Milling can either precede or follow blending. The prepared coal blend, typically 85 to 90 percent in sizes below 1/8 inch, is transferred to a storage silo or bunker atop the battery of ovens. (A typical overall process flowsheet is illustrated in Figure II-1.)

For the charging of each oven, a weighed amount of prepared coal is discharged from the bunker into the larry car, a wide-gauge vehicle which can traverse the entire length of the battery. The larry car is fitted with hoppers to carry the coal and with discharge chutes for transfer of the coal into the slot retorts. Table or screw feeders may be used to control the flow of coal from the hoppers. As shown in Figure II-2, the larry car is positioned over the empty oven, lids covering the coal-charging ports are removed, and the coal is discharged to the retorts either simultaneously from all hoppers or in prearranged sequence if necessary for even filling.

The charged coal peaks under the charging ports. To eliminate the peaks, a leveling bar of structural steel is pushed back and forth across the top of the charge, from a port at one end door. The port for the leveling bar is called the chuck door, and is used only for this purpose. After the coal has been leveled, all ports except the standpipe are sealed, and coking proceeds. Typically, 15 to 18 hours is required to produce good blast-furnace coke in an 18 to 20-inch-wide oven. The coking time is determined by the coals, the coal moisture, and the rate at which the interwall heating flues are fired. Coke-oven firing arrangements are complex (see Figures II-3 and II-4 for typical cutaway views of the brickwork), and each designer claims advantages for his own particular configuration of flues. With minor exceptions (to be covered), details of flue arrangement do not affect the air-pollution behavior of a coke-oven plant.

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*An oven can be cooled such that the brickwork is preserved, but the procedure is lengthy and expensive.

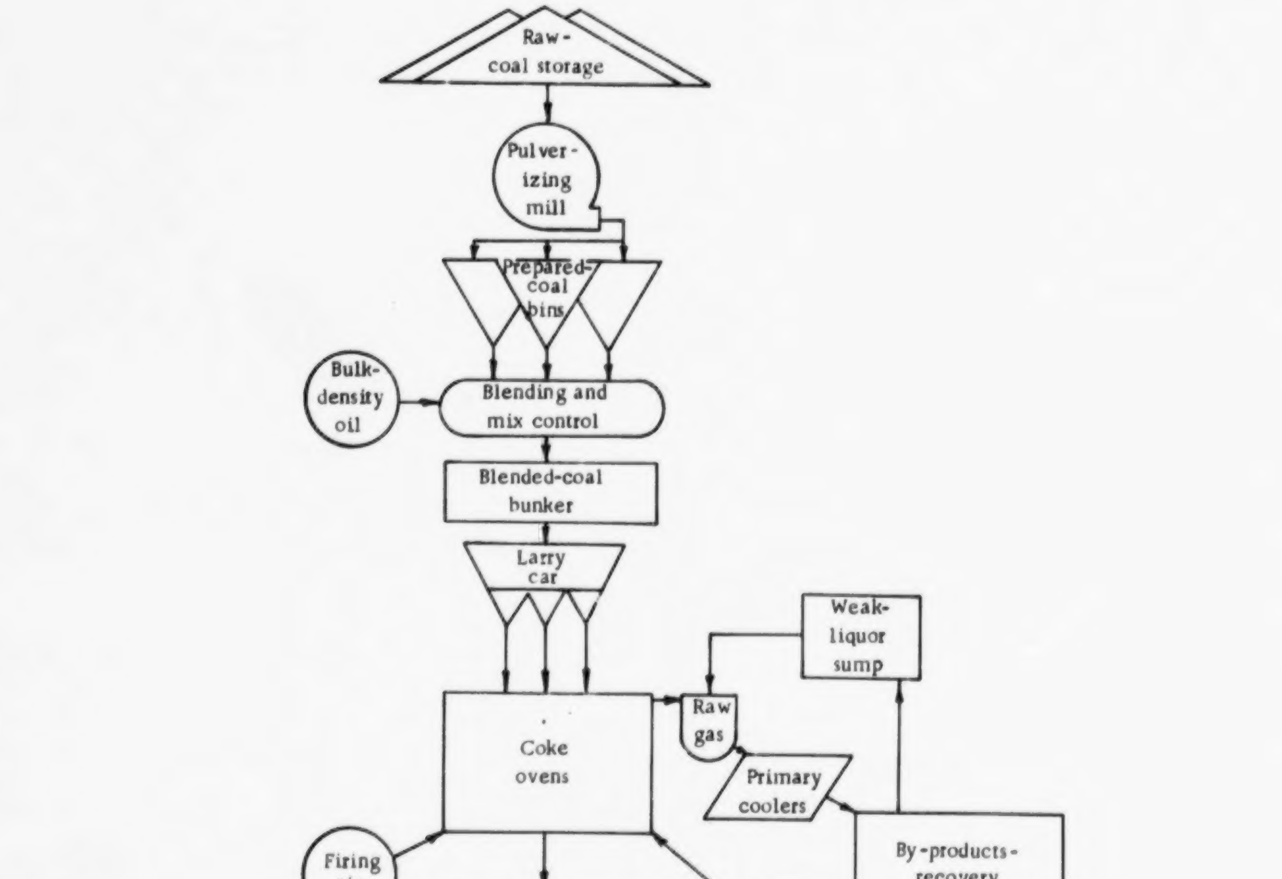
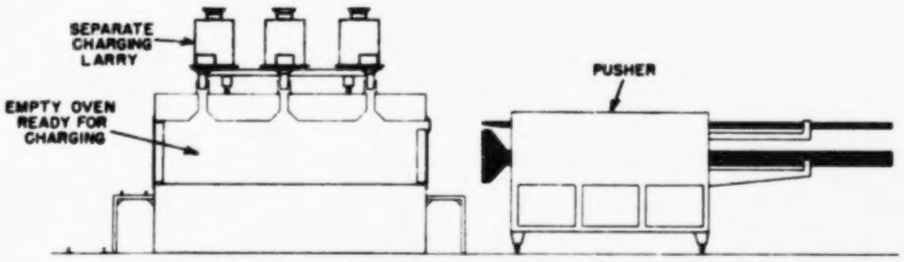
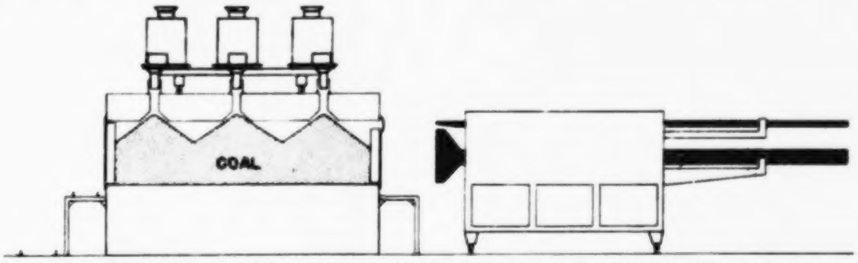

Raw-coal storage
Pulverizing mill
Prepared-coal bins
Bulk-density oil
Blending and mix control
Blended-coal bunker
Larry car
Weak-liquor sump
Raw gas
Coke ovens
Primary coolers
Firing air
By-products-recovery systems
Hot-coke car
Fuel gas, 550 Btu
Surplus gas
Quench-water sump
Quench tower
Tar and chemicals to market
Coke wharf
Coke crusher
Furnace sizes (+3/4)
Screens
Blast furnace
Nut and breeze
Sintering and other uses

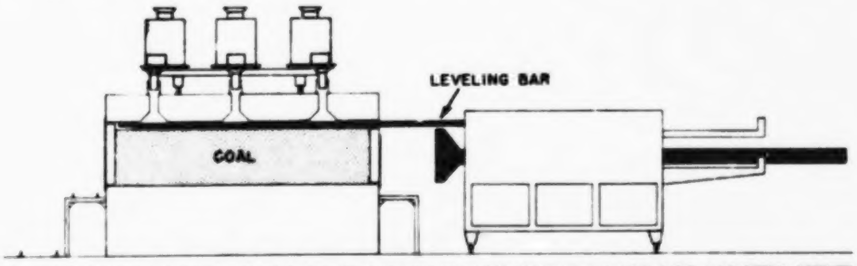
FIGURE II-1. FLOW SHEET SHOWING THE MAJOR STEPS INVOLVED IN THE CARBONIZATION OF COAL BY THE BY-PRODUCT PROCESS



A. THE CHARGING LARRY, WITH HOPPERS CONTAINING MEASURED AMOUNTS OF COAL, IS IN POSITION OVER CHARGING HOLES FROM WHICH COVERS HAVE BEEN REMOVED. THE PUSHER HAS BEEN MOVED INTO POSITION.



B. THE COAL FROM THE LARRY HOPPERS HAS DROPPED INTO THE OVEN CHAMBER, FORMING PEAKED PILES.



C. THE LEVELING DOOR AT THE TOP OF THE OVEN DOOR ON THE PUSHER SIDE HAS BEEN OPENED, AND THE LEVELING BAR ON THE PUSHER HAS BEEN MOVED BACK AND FORTH ACROSS THE PEAKED COAL PILES TO LEVEL THEM. THE BAR NEXT IS WITHDRAWN FROM THE OVEN, THE LEVELING DOOR AND CHARGING HOLES ARE CLOSED, AND THE COKING OPERATION BEGINS.

FIGURE II-2. SCHEMATIC REPRESENTATION OF CHARGING AND LEVELING OPERATIONS FOR A BY-PRODUCT COKE OVEN

Source: United States Steel Corporation

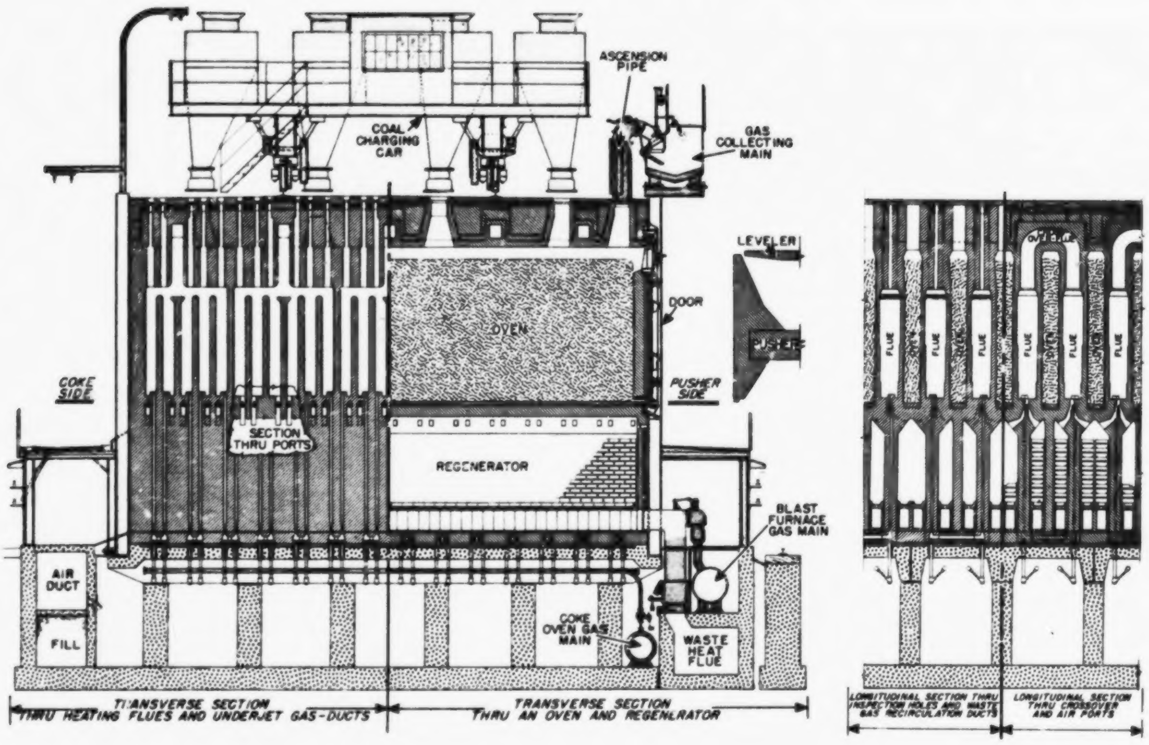

ASCENSION PIPE
COAL CHARGING CAR
GAS COLLECTING MAIN
LEVELER
DOOR
OVEN
PUSHER
COKE SIDE
PUSHER SIDE
SECTION THRU PORTS
REGENERATOR
BLAST FURNACE GAS MAIN
AIR DUCT
FILL
COKE OVEN GAS MAIN
WASTE HEAT FLUE
FLUE
OVEN
TRANSVERSE SECTION THRU HEATING FLUES AND UNDERJET GAS-DUCTS
TRANSVERSE SECTION THRU AN OVEN AND REGENERATOR
LONGITUDINAL SECTION THRU INSPECTION HOLES AND WASTE GAS RECIRCULATION DUCTS
LONGITUDINAL SECTION THRU CROSSOVER AND AIR PORTS

FIGURE II-3. TRANSVERSE AND LONGITUDINAL SECTIONS THROUGH KOPPERS-BECKER UNDERJET-FIRED LOW-DIFFERENTIAL COMBINATION BY-PRODUCT COKE OVENS

Source: United States Steel Corporation

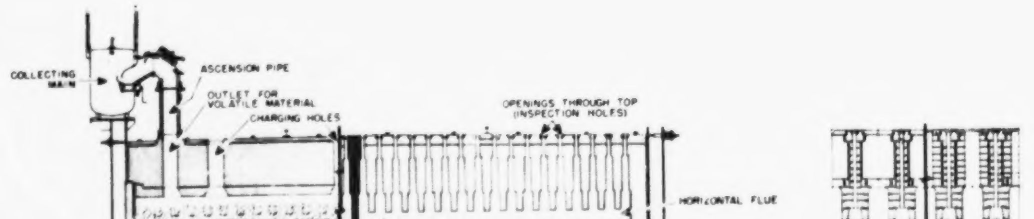
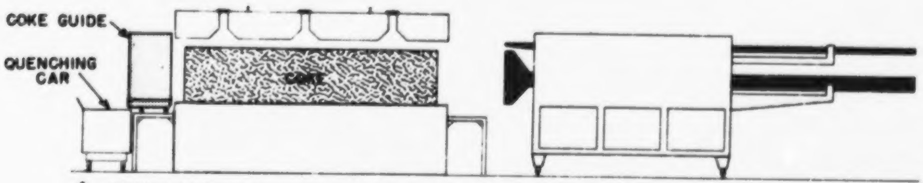

COLLECTING MAIN
ASCENSION PIPE
OUTLET FOR VOLATILE MATERIAL
CHARGING HOLES
OPENINGS THROUGH TOP (INSPECTION HOLES)
HORIZONTAL FLUE
COKE SIDE
PUSHER SIDE
OVEN
VERTICAL FLUES
DOOR
HIGH BURNER
LOW BURNER
OUTER ZONE REGENERATOR
INNER ZONE REGENERATOR
WASTE GAS FLUE
AIR INTAKE
DIVISION WALL
RICH GAS MANIFOLD
LEAN GAS MAIN
DECARBONIZING AIR
RICH GAS MAIN
COMBUSTION AIR INLET TO BASEMENT
FLUE
OVEN
BUS FLUE TO OUTER ZONE
BUS FLUE TO INNER ZONE
TRANSVERSE SECTION THROUGH OVEN AND REGENERATORS
TRANSVERSE SECTION THROUGH FLUES, BURNERS AND UNDERJET GAS-DUCTS
LONGITUDINAL SECTION THRU INSPECTION HOLES AND AIR PORTS
LONGITUDINAL SECTION THRU BURNERS AND CHARGING HOLES

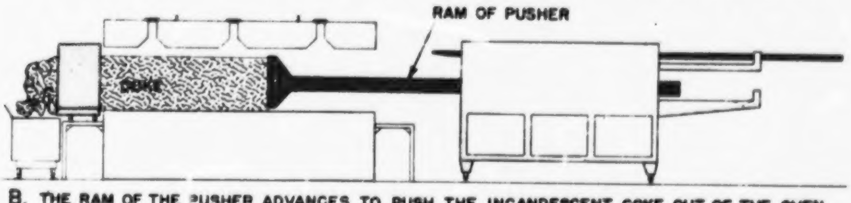
FIGURE II-4. SECTIONS THROUGH A BATTERY OF WILPUTTE UNDERJET, COMBINATION OF BY-PRODUCT OVENS (DESIGNATED AS "DOUBLE-DIVIDED" OVENS, HAVING TWO OUTER ZONES AND ONE DOUBLE INNER ZONE IN THE HEATING SYSTEM)

Source: United States Steel Corporation

At the end of the coking cycle, both end doors are removed, and the coke is pushed out one end of the retort by a ram. This operation is illustrated in Figure II-5. The ram is mounted on a wide-gauge vehicle traveling along one side of the battery. This vehicle, called a pusher machine, also carries the leveler bar. The coke is received into a hopper car (of specialized design) traveling on the other side of the battery, and is carried in that car to a chimneylike tower wherein it is deluged with water to quench it from its original 2000 F+ temperature as pushed. The quenched coke enters the coke-handling and -conveying system from a sloping wharf which receives the quenched coke from the hopper car and allows it to drain, steam, and/or cool until reasonably uniform in temperature and moisture. Coke is sometimes crushed in a finger crusher before use, and is invariably screened to remove fines and small intermediate sizes. Coke sent to blast furnaces is usually the fraction passing over a 3/4 to 1-inch screen, depending on the plant's need for furnace sizes.



A. COKING OF THE COAL ORIGINALLY CHARGED INTO THE OVEN HAS BEEN COMPLETED (IN ABOUT 18 HOURS) AND THE OVEN IS READY TO BE "PUSHED." THE OVEN DOORS ARE REMOVED FROM EACH END, AND THE PUSHER, COKE GUIDE AND QUENCHING CAR ARE MOVED INTO POSITION.



B. THE RAM OF THE PUSHER ADVANCES TO PUSH THE INCANDESCENT COKE OUT OF THE OVEN, THROUGH THE COKE GUIDE AND INTO THE QUENCHING CAR.

FIGURE II-5. SCHEMATIC REPRESENTATION OF PUSHING OPERATIONS FOR A BY-PRODUCT COKE OVEN

Source: United States Steel Corporation.

A more complete description of conventional coking is given in The Making, Shaping, and Treating of Steel (8th Ed., United States Steel Corporation, 1964). (Some of the figures in this part of the report are taken from that text by permission.) The thermochemistry of coal which determines coking mechanisms is well presented in Chemistry of Coal Utilization, Supplementary Volume (Wiley, New York, 1963).

Our Dependence on Coke

Coke has previously been defined in the sense of a product made by thermal destruction of coal under controlled conditions. Coke may also be defined as a strong, solid, stable, yet reactive form of carbon. These characteristics of coke make it usable for the smelting of iron in the blast furnace, a process which is exceptionally demanding in regard to fuel characteristics.

In the blast furnace, coke descends along with iron ore and other charges from the top toward the bottom. (See Figure II-6 for a conceptual presentation of the blast-furnace process.) The coke reacts very little at the low temperatures that exist high in the furnace, but may react to some extent with carbon dioxide in the hotter zones where iron ore is reacting rapidly with the reducing gases. The back-reaction of coke with carbon dioxide regenerates reducing gases and may actually help balance the process under conditions of high production. But the main role of coke is not played until it has descended into the bosh zone, where all charged solids except coke become molten. In the bosh, which contains principally a porous bed of hot coke, the coke physically supports the entire solid burden and at the same time performs three vital thermochemical functions:

(1) It generates reducing gas via reaction with the hot air blast.

(2) It generates all required process heat excepting that provided by sensible heat in the blast.

(3) It acts as a superheated refractory heat exchanger to transmit high-temperature heat to the iron and slag trickling toward the crucible.

The blast furnace as now conceived will not work without a reactive, strong, stable, "combustible refractory" typified by coke. Several other types of furnaces, notably the foundry cupola, depend on coke for similar reasons. Attempts to design an alternative form of countercurrent smelting reactor which can operate with coal, oil, or gas as the principal fuel have been made for over 100 years, but with only limited success.

This is not to say that the blast furnace has no challengers. In the years since World War II, so-called "direct reduction" processes (a misnomer) have been promoted vigorously, and in some locations they make good economic sense. As the price of prime coking coals climbs higher, certain direct-reduction processes will probably gain some acceptance in the American steel industry. But while our prime coking coals last, or if we learn to coke coals now considered marginal, the blast furnace will hold a strong place because it is big, efficient, and inexpensive in terms of cost above materials. Accordingly, wherever alternatives to slot-retort coking are considered in this report, they are considered as alternatives that can in fact produce blast-furnace coke. Alternatives to the use of coke are not considered because in our present mix of natural resources they are rarely competitive.

Some Macroeconomic Factors

To complete this background on the coking process, it is appropriate to consider the importance of coke as an economic entity, especially because the man-in-the-street rarely sees this product. Primary references for the ensuing economic summary are the AISI Annual Statistical Report for 1968 and the 1968 edition of Bituminous Coal Data, published by the National Coal Association.

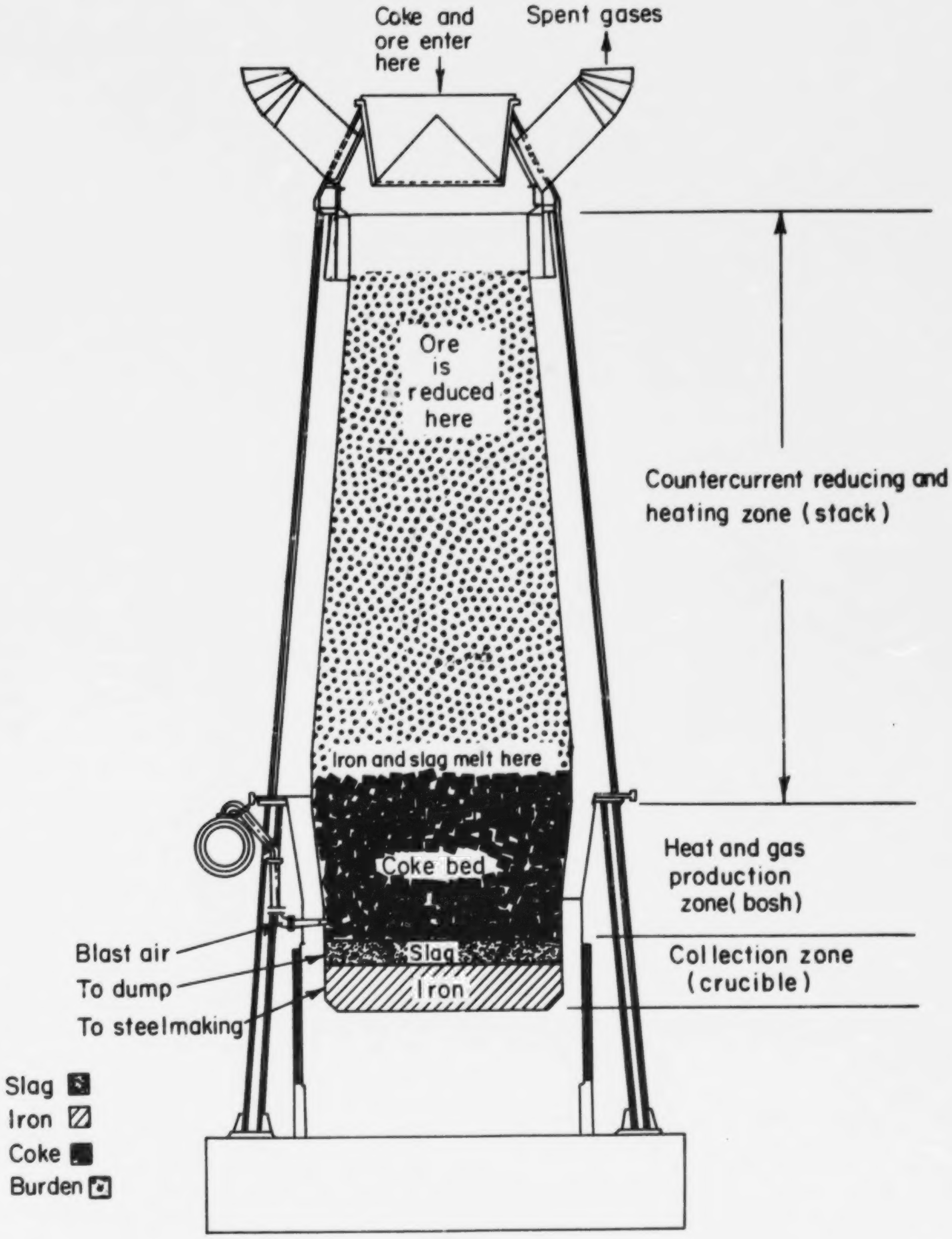

Coke and ore enter here
Spent gases
Ore is reduced here
Countercurrent reducing and heating zone (stack)
Iron and slag melt here
Coke bed
Heat and gas production zone(bosh)
Blast air
To dump
To steelmaking
Slag
Iron
Collection zone (crucible)
Slag
Iron
Coke
Burden

FIGURE II-6. THE BLAST FURNACE

Production and Consumption of Coke

In 1968, according to AISI figures, the net new supply of coke to the United States iron and steel industry was as follows:

	Million Net Tons
Production of Coke by Steelmakers	56.990
Purchases From Merchant Producers	3.150
Less:	
Shipments to Nonsteelmakers	(1.587)
Losses on Intercompany Transfer*	(0.045)
Losses on Interplant Transfer*	(0.399)
Net New Supply of Coke at Use Sites	58.109

In addition to producing over 3 million tons of merchant coke for the iron and steel industry, merchant coke producers produced about 3 million tons of coke for foundries and other users. Statistics given in this section refer only to coke used by the integrated iron and steel industry.

The apparent consumption of coke in 1968 was:

	Million Net Tons
Coke Charged to Blast Furnaces	57.619
Coke Used in Captive Foundries	0.015
Coke Applied to Other Uses	0.179
Coke Used as Breeze in Sintering	2.248
Less:	
Coke Breeze Recovered at Blast Furnaces (Used Elsewhere)	(1.381)
Net Apparent Consumption	58.680
Apparent Change in Stocks (Decline)*	0.571

The AISI statistics do not clarify whether transfer losses shown in the supply tabulation become available for use as breeze in sintering; if so, the net decline in coke inventories was less than indicated.

Figure II-7 presents data on new coke supply, computed as in the 1968 example, for the years since 1962. On the right-hand scale, the production of blast-furnace iron and blast-furnace ferroalloys is shown for comparison. It is clear from

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*Inferred.

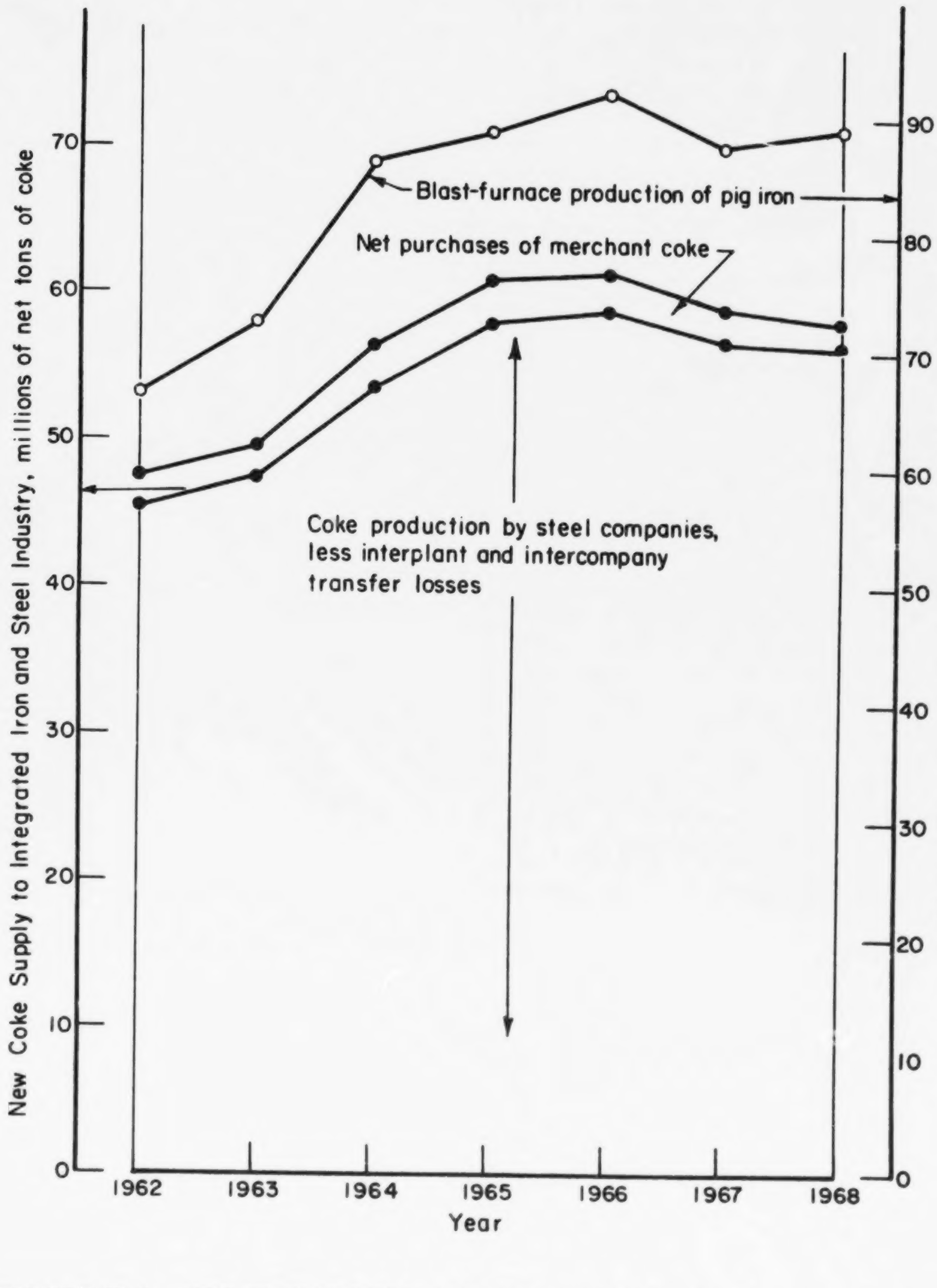

FIGURE II-7. NET PRODUCTION AND NET PURCHASES OF COKE BY THE INTEGRATED IRON AND STEEL INDUSTRY, RELATED TO BLAST-FURNACE PRODUCTION

Figure II-7 that iron production governs coke production quite closely. Although the coke consumption per ton of blast-furnace iron is in steady decline (see Figure II-8), there is some indication that this trend may be slowing now that most U. S. blast furnaces are using injected auxiliary fuels and beneficiated burdens.

It is difficult to visualize the meaning of 58+ million net tons of coke. However, two volumetric references, based on a typical in-pile bulk density of 30 pounds per cubic foot, may help. In terms of a stockpile 1 mile in diameter and conical in shape, the net new supply of coke to steelmakers in 1968 would form a pile about 530 feet high. In terms of flow through a pipe 1 square foot in cross section, new coke supply would have to move at nearly 123 feet per second (72 miles per hour) night and day. For the United States, in 1968 the bulk volume of coke produced was roughly half the volume of concrete placed for highways, dams, buildings, and all other purposes.

With regard to the future use of coke, Battelle has prepared the following estimates of coke demand based upon anticipated blast-furnace production and probable continued decline of unit coke requirements per ton of iron smelted:

1970 – 65 million tons of coke for the steel industry

1975 - 69 million tons

1980 - 74 million tons.

The demand for coke outside of the integrated iron and steel industry is likely to remain at its present level of roughly 6 million tons of coke annually, and this amount may be added to the cited steel-industry projections to give overall estimates. Coke from beehive ovens, typically less than 2 percent of total coke, is expected to decline further in importance. The sensitivity of beehive coke production to changes in total coke demand is illustrated by consideration of statistics for 1967 compared with data for 1966. A 44 percent drop occurred in production of beehive coke for 1967. This drop corresponded to a decline in total coke production of only 4.2 percent, thus the leverage of total coke demand upon beehive coke production was roughly 10:1.

Cost and Investment for Coking

The U.S. Bureau of Mines regularly publishes data illustrating the value of coke. From 1962 to 1967, inclusive, this figure for nonmerchant coke plants (those in the steel industry) ranged from a low of \$16.21 to a high of \$17.71 per net ton. The 1966 and 1967 figures were close to \$16.70, and the 1968 figure was \$16.40. A sharp rise is expected for 1969 and 1970.

This composite valuation reflects contributions from both high-cost and low-cost areas. For example, coke costs more in the Chicago area than in Pittsburgh, if only because the coals (or some of them) must be shipped longer distances. A representative cost structure (based upon average coal-shipping costs) reasonably might be about as follows for 1 net ton of blast-furnace coke produced in 1969:

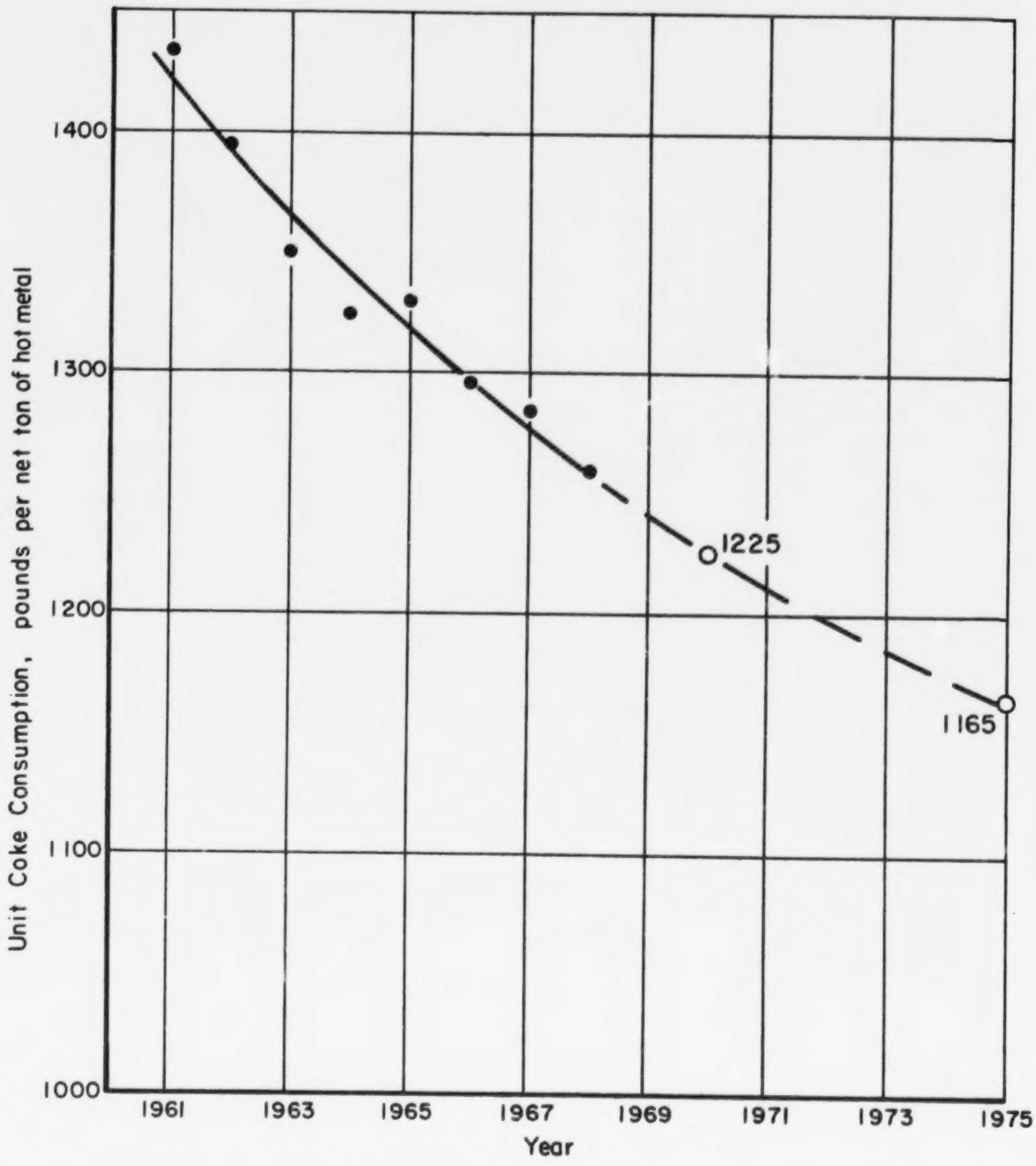

FIGURE II-8. THE DECLINING UNIT CONSUMPTION OF BLAST-FURNACE COKE PER TON OF IRON

Solid points are from AISI reports; open points are Battelle forecasts.

	Dollars per Net Ton of Furnace Coke	
Coal (About 1.5 Net Tons, Average Unit Cost Approximately $7.00 FOB Mines)	10.50	
Coal Shipping (Average $3.00 per Net Ton)	4.50	
Direct Costs Above Coal (Labor, Maintenance, Utilities, Materials, and Supplies)	5.30	(± 1)
Credits for Coke Fines, Gas, Tar, Light Oils, etc. (Net of Steam and Acid Costs)	(4.60)	(± 1)
Indirect Factors (Depreciation, Capital Charges, Taxes, Insurance, General and Corporate Overheads)	2.50	(± 1)
Total (Representative or Typical Value)	18.20	(± 3)

The variances shown arise from differences in location, in coal-supply arrangements, in markets for by-products, and especially in accounting policy and procedure. The total of $18.20 is expected to be within $1 of the 1969 Bureau of Mines valuation for coke produced in furnace plants. Coke costs have taken a sharp jump during 1969 owing to a severe coal shortage plus general inflation. The market value of coking by-products has been under intense pressure from petroleum-based fuels and chemicals.

The significant concepts to be drawn from the above tabulation of coke value factors are these:

(1) Slot-oven coking gets a lot of economic help from its by-products, the revenue from which often pays 90 percent or more of direct costs above coal. This is significant when considering the cases of form-coking or other coking methods wherein by-products are not recovered.

(2) Despite low public awareness of coke as a product, it is very significant in our economy. At the above valuation, current coke production by and for steelmakers amounts to over $1.1 billion dollars annually.

There are few authoritative sources of information about the cost of new coking facilities. All available information plus help from coke-plant builders was used by Battelle in 1967 to prepare some estimates of coke-plant cost, excluding land and facilities for handling coal and coke. These 1967 estimates, inflated about 15 percent to adjust to 1969 construction costs are as follows:

	Estimated Construction Cost in 1969, per Annual Ton of Coke, dollars[a]		
New Plant on Green-Field Site			
Coke plant exclusive of by-products plant	33	to	34
By-products plant; complexity appropriate to size of coke plant	13	to	14
Total (excluding land and coal and coke handling)	46	to	48
Rebuilding of Battery			
Battery rebuilt on existing foundation; no changes in by-products plant	17	to	18

[a] Generally these figures are relatively insensitive to scale.

On this basis, the present replacement value of existing steelworks' coke plants "in kind" is on the order of $3 billion. These capital and replacement costs as discussed here are for coke ovens that have air-pollution controls of the general type commonly used prior to 1970 – that is, for coke ovens that contribute substantially to air pollution. Ovens that include more effective controls of the types discussed in this report will cost substantially more.

SECTION III

CONVENTIONAL COKING

The details of two alternative paths toward the alleviation of coking emissions are presented in Sections III and IV. The alteration and improvement of existing (or future) conventional coke plants are discussed in Section III. The possible adoption of new coking processes which may be configured (at least potentially) to avoid emissions is discussed in Section IV.

The conventional slot-oven coking of bituminous coals (described in Section II) is a batch process. In effect, the slot oven is a batch chemical retort which is charged, heated according to a predefined program, then discharged on a regular cycle. Activities peripheral to manufacturing of coke may also be batch operations, geared to the coke-oven schedule (as in the case of quenching), or they may be partly or fully continuous. Processing of by-products is a good example of a continuous operation, whereas handling of coal and coke may be intermittent or semicontinuous. The principal air-polluting operations in conventional coking are associated with the batchwise steps of charging and pushing the ovens.

In Figure III-1 the general coking flowchart of Figure II-1 is repeated, with the addition of a red outline which encloses those processes that have been specifically studied during this program. Process segments excluded from consideration are (1) coal unloading and outdoor storage, (2) coke-plant by-products processing, and (3) coke and by-products distribution and use. The red outline on Figure III-1 passes midway through the symbol for coke-oven gas to signify that this study is concerned with the use of coke-oven gas for underfiring the coke ovens. Similarly, the study has been concerned with the effects of various emission controls upon the accumulation of solids in the raw-gas collector system and the primary coolers.

This section of the report is organized into seven topical subsections, mainly oriented toward the potential sources of emissions:

(1) Handling, crushing, and blending of coals; handling and screening of coke

(2) Charging of coal into the slot ovens

(3) Underfiring the slot ovens with coke-oven gas

(4) Sealing of slot ovens during early stages of coking

(5) Discharging of newly produced coke

(6) Quenching of hot coke

(7) Miscellaneous problems and opportunities.

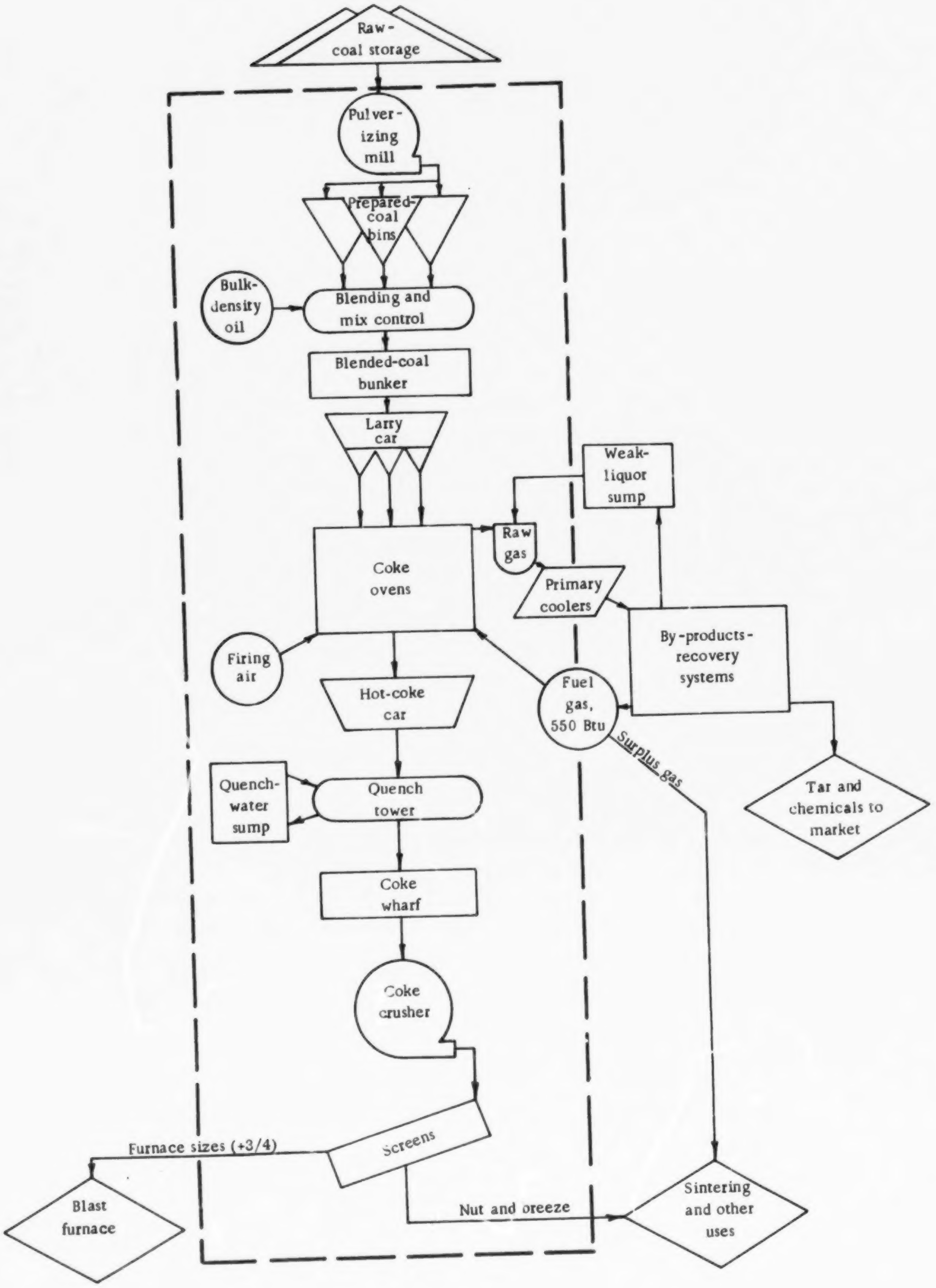
Raw-coal storage
Pulverizing mill
Prepared-coal bins
Bulk-density oil
Blending and mix control
Blended-coal bunker
Larry car
Weak-liquor sump
Raw gas
Coke ovens
Primary coolers
By-products-recovery systems
Firing air
Hot-coke car
Fuel gas, 550 Btu
Surplus gas
Tar and chemicals to market
Quench-water sump
Quench tower
Coke wharf
Coke crusher
Screens
Furnace sizes (+3/4)
Blast furnace
Nut and breeze
Sintering and other uses

FIGURE III-1. FLOWCHART FOR CONVENTIONAL SLOT-OVEN COKE PLANT

Red dashed line indicates scope of this study.

Within each of the subsections, the information presented includes:

- Nature of apparatus and operations giving rise to emissions
- Types, characteristics, and amounts (where known) of emissions
- Practices and apparatus for alleviation of emissions.

Where alternative approaches and methods exist (particularly in the cases of charging, discharging, and quenching), comparisons are presented, but evaluations and recommendations have been reserved to Section V.

Handling, Crushing, and Blending of Coals; Handling and Screening of Coke

Coals for conversion to coke must be pulverized so that a major portion (typically 80 percent) is in particles smaller than 1/8 inch. Also, coals with differing coking properties must be carefully proportioned and thoroughly blended before they are charged to the coke ovens. Coke, after it has been quenched, must be screened to remove the smaller sizes before the larger sizes can be sent to the blast furnace. In cases where the natural top size of coke is considered too large, finger crushers may be used ahead of the screens.

Apparatus and Operations

The general layout of a coal-handling plant, much simplified, is illustrated in Figure III-2. As in Figure III-1, the red outline indicates that this study is not concerned with the unloading, stocking, or reclaiming of coal. The principal dust-raising operation is pulverizing, but this is usually performed in a totally enclosed hammermill so that escape of dust from the mill is low. Not shown in the layout are the dozens of conveyors, chutes, feeders, and elevators used to transfer the coal from stage to stage of preparation. Consideration of coal handling begins where the coal enters the conveying and processing system, usually from a car dump or receiving hopper. The end point is at the discharge of coal from the blended-coal bunkers into the larry car used to charge the ovens.

The functional layout of a coke-screening station is illustrated in Figure III-3, and again the red line indicates limits of this study. Usual American practice separates coke into three sizes called furnace coke, nut coke, and breeze. The screen openings for these separations vary from plant to plant and according to plant requirements for the various types. Some plants grind nut coke to make additional breeze for sintering; others sell it for use in electric smelting of alloys. Many modern coke-handling plants are equipped with top-size crushers to break up pieces bigger than 3 to 4 inches, but this operation produces additional breeze and is bypassed during periods of coke shortage. Concern of this study with coke-handling emissions begins with the dumping of newly quenched coke on the wharf, and ends with final load-out of screened fractions to cars or conveyors bound for points of use. As in the case of coal handling, the layout in Figure III-3 does not show conveyors, chutes, and feeders used in moving the coke from

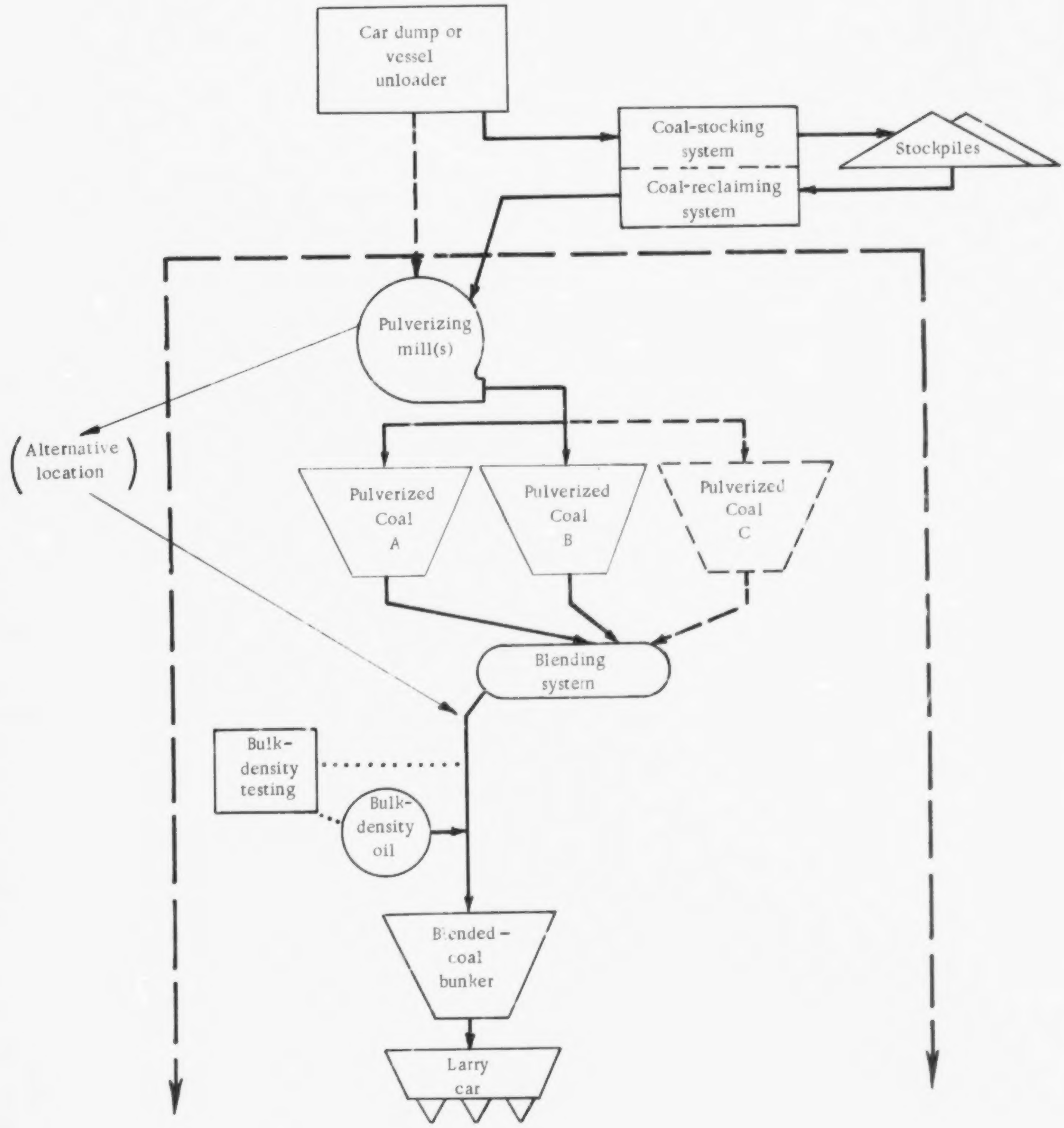
Car dump or vessel unloader
Coal-stocking system
Stockpiles
Coal-reclaiming system
Pulverizing mill(s)
(Alternative location)
Pulverized Coal A
Pulverized Coal B
Pulverized Coal C
Blending system
Bulk-density testing
Bulk-density oil
Blended-coal bunker
Larry car

FIGURE III-2. GENERALIZED COAL-HANDLING SYSTEM

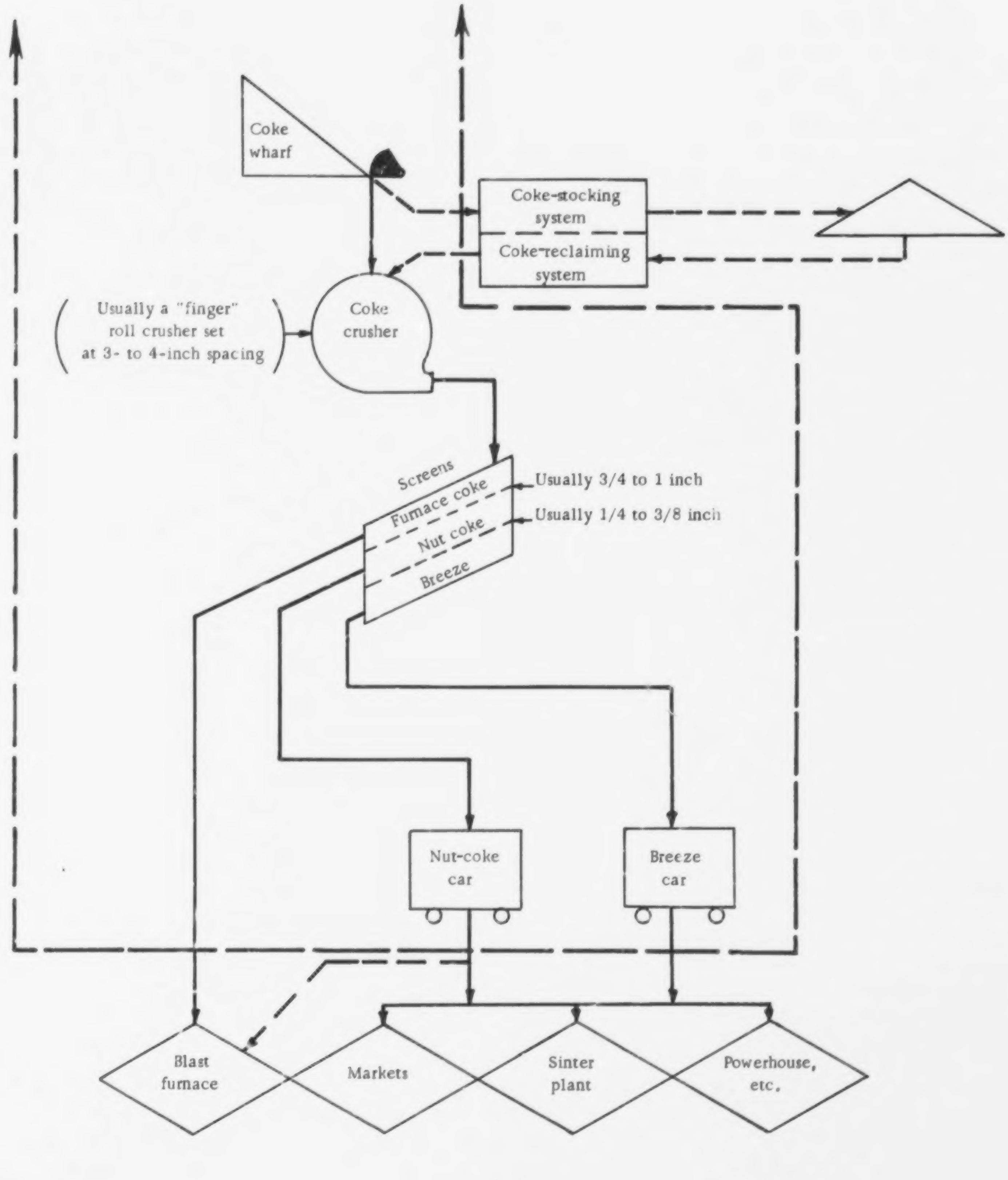
Coke wharf
Coke-stocking system
Coke-reclaiming system
Usually a "finger" roll crusher set at 3- to 4-inch spacing
Coke crusher
Screens
Furnace coke
Nut coke
Breeze
Usually 3/4 to 1 inch
Usually 1/4 to 3/8 inch
Nut-coke car
Breeze car
Blast furnace
Markets
Sinter plant
Powerhouse, etc.

FIGURE III-3. GENERALIZED COKE-HANDLING SYSTEM

step to step. Coke-handling facilities are usually less complicated than coal-handling facilities, in part because no surge bunkers or bins are required.

For this study, the coal-handling and coke-handling operations are considered together, even though in a typical plant they may be separated by hundreds of yards. The reason for joint consideration is that there are strong similarities in causes, types, and amounts of emissions, such that the appropriate countermeasures are similar. In handling of both coal and coke, the principal release of emissions originates from free fall of the materials at transfer points and during mechanical processing steps. In both cases, release of dusts to the air is usually via natural ventilation of the work area, and can become pronounced when a brisk breeze interacts with accumulated, dried spillage of coal and coke fines.

Emissions

The primary emissions from handling of coal and coke are, respectively, coal dust and coke dust. For airborne release, the particle sizes average well below 0.1 millimeter, and suspended fractions are in the range of 1 to 10 microns. These particles are originally released when materials escape from free-fall at the transfer points, or are violently agitated in mechanical operations such as pulverizing or screening. However, handling losses do not necessarily become air pollution. Dusts may be released to the outside air from the buildings "at large", through windows, doors, eaves ports, roof vents, and unenclosed areas. The rate of release to the outside air is sensitive to wind direction and velocity; a high wind following a period of dry weather can have a striking effect.

Secondary emissions may include rust and rubber fines produced by the wearing or rusting of process equipment, but these particles are minor in amount and usually are absorbed into the stream of material in process. Where distillate oil is used to adjust the bulk density of the coal, some oil vapor may be noticeable above conveyors and bins.

The amounts of coal dust and coke dust lost during processing have been estimated in private communication with a midwestern American coke plant and by European experts contributing to a United Nations document.(1) In the American case, it appears that from 0.2 to 0.5 percent of coal weight received (dry basis) is lost from all causes between rail-of-vessel and the larry car. Much of this is via washing of fines from storage piles by rain. Some is carried away by wind during outdoor handling and storage. It is estimated that about 20 percent of total losses of coal occur as dust from the pulverizing and blending operations. This leads to an estimate of 0.05 to 0.1 percent dust losses within the coal-handling plant, some fraction of which may become air pollution. Coke-handling losses are believed to be somewhat less.

The above estimates agree with French figures for losses from a plant handling 1000 to 1200 tons of coal per day. Samples taken on one floor of a coal-handling building showed 0.03 percent losses, and these were judged to represent half of the total process losses. Thus the French estimate, 0.06 percent, is near the lower end of the previously cited range.

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(1) Air Pollution from Coking Plants, United Nations Economic Commission for Europe, 1968. (ST/ECE/COAL/26)

In sharp contrast, Czech figures for actual emissions from a plant equipped with dust-control equipment indicate emissions of only 0.01 percent, mostly via the escape of dust through the dust collectors. Thus, for this case, emissions to the air seem to represent only about 10 percent of losses.

From these meager data, it is surmised that total losses from the coal-handling system may range from 0.01 to 0.1 percent, and that coke-handling losses are typically less than 0.01 percent. Only a fraction of these losses enter the air, and of these only a fraction escape the plant. There simply is no way of determining how much coal and coke dust from this source becomes air pollution and how much is absorbed into the plant soils. The balance shifts from day to day, depending on wetness and wind velocity.

Notice that new continuous coking processes must include both the pulverization of coals and the removal of coke fines abraded from the briquettes or other shapes. Accordingly, the considerations of control explored in the following paragraphs apply to all coking processes.

Alleviation

The present status of U. S. coal-handling and coke-handling operations is that simple lightweight buildings and galleries are generally provided to protect the equipment. The usual construction of these enclosures is steel framing with galvanized or asbestos-coated corrugated steel siding and roofs, and with poured concrete floors. Windows and doors are provided, and some galleries have gutters molded into the concrete floors to facilitate hosing-down for housekeeping purposes. In dusty areas, workmen commonly remove wall panels, open windows, or block doors open so that added ventilation may be obtained.

Dust-suppression devices include steel-plate shrouding of handling sites and transfer points, often with rubber skirts and aprons to extend shrouding down to the edges of the conveyor belts. Some plants discharge "soft" (condensing) steam into shrouds at the bottoms of chutes, so that some dust particles are wetted and tend to agglomerate. At exceptionally dusty sources, enclosed shrouds and drafted hoods are provided to draw the dust off into cyclones or other dust collectors. However, only partial shrouding and enclosure have been provided for most entry and exit points such as coal-car dumps, coal-receiving hoppers, coke wharves, discharge chutes between coal bunkers and larry cars, and discharge chutes between screening stations and the rail cars receiving nut and breeze coke. The overall emission of dust to the outside air from most existing coal-handling and coke-handling plants depends on housekeeping and weather, because internal suppression of dust is incomplete and sources are not fully enclosed. Newer plants incorporate centralized vacuum-cleaning power units, with outlets spaced conveniently to facilitate better housekeeping.

Implementation of air-quality regulations will almost certainly require coke producers to take three kinds of steps:

(1) Full enclosure of coal-handling and coke-handling plants, and improved enclosure of entry and exit points

(2) Improvements and additions to existing systems of shrouds, hoods, seals, and dust collectors

(3) Increased use of dust-retarding methods such as wetting.

From the community viewpoint, enclosure of coal- and coke-handling operations within virtually weathertight buildings should almost end the problems of dust from these activities. The augmentation of dust-removal systems and other measures taken inside the buildings will be dictated by the need to provide for working conditions free of health and fire hazards. Note however, that this will overcome only about 20+ percent of the overall coal-dust problem; similarly, effective measures will be needed for coal receiving, storage, and reclaiming activities.

The technology of building and gallery enclosure is not complicated. Some of the steps to be taken include removal of clerestories and other uncontrolled vents, repair of broken windows, panels, and doors, and closure of the free spaces normally left between sidewall panels and either roofs or floors. At entry and exit points, improvement of enclosures requires building around and over the ports, contiguous with the main buildings, as fully as is possible. It is difficult to provide much more than a tunnel for rail cars or coal-reclaim vehicles, but there are ways to design the tunnels so that their ends are partly blocked by the cars themselves.

The technology of shrouding, hooding, and dust collection is well developed, and some of the required configurations have already been designed and applied. Some illustrative details have been reproduced from a German technical paper in Figures III-4, III-5, and III-6.(2) Figure III-7, from the same source, gives an example of unified dust-collecting equipment applied to a coke-handling plant. Most U. S. plants have some of this apparatus but will need to install more.

Where drafted systems of enclosures fail to contain or control dust adequately, the next-best approach is by wetting the dusty materials. Work done by the U. S. Bureau of Mines in 1966 showed that use of wet blast-furnace coke (completely soaked by spraying) did not seem to detract from either the productivity or the fuel economy of the smelting operation.

Unfortunately, the soaking of coals is not potentially as feasible as the soaking of coke. Each 1 percent of moisture added to coking coal produces a 2 percent increase in (practical) requirements for coking heat.* Thus, productivity of coke from wet coal drops if the heating rate of the oven is unchanged. Also, within the coal-handling system, overwetted coals would stick to everything and would tend to foul the transfer points, the bunkers, and the larry car. Thus the wetting of coals for dust suppression must be limited to judicious use of fine sprays or condensing steam. In some cases, it might be feasible to apply bulk-density oil to powdery low-volatile coals as they enter the plant.

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(2) Engels, Lothar, H., "Entstaubungstechnik and Reinhaltung der Luft in den Übertagigen Anlagen des Steinkohlenbergbaus", ("Dust Removal Technique and Air-Quality Control in Above-Ground Coal Operations"), Bergfreiheit, 1966, 28 pp.

*The theoretical increase in heat requirements is 11+ Btu per pound of coal, and heating efficiency is taken to be 50 percent.

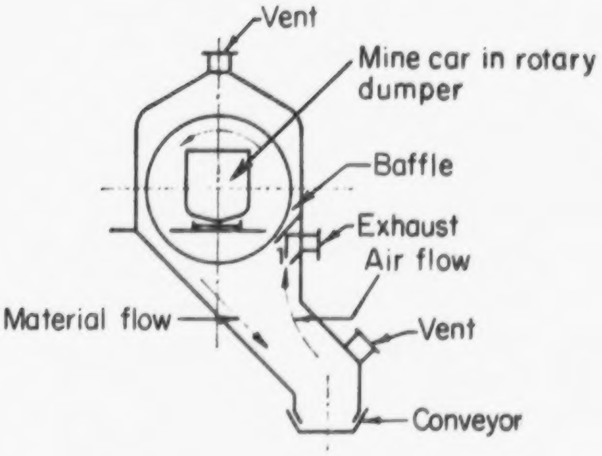
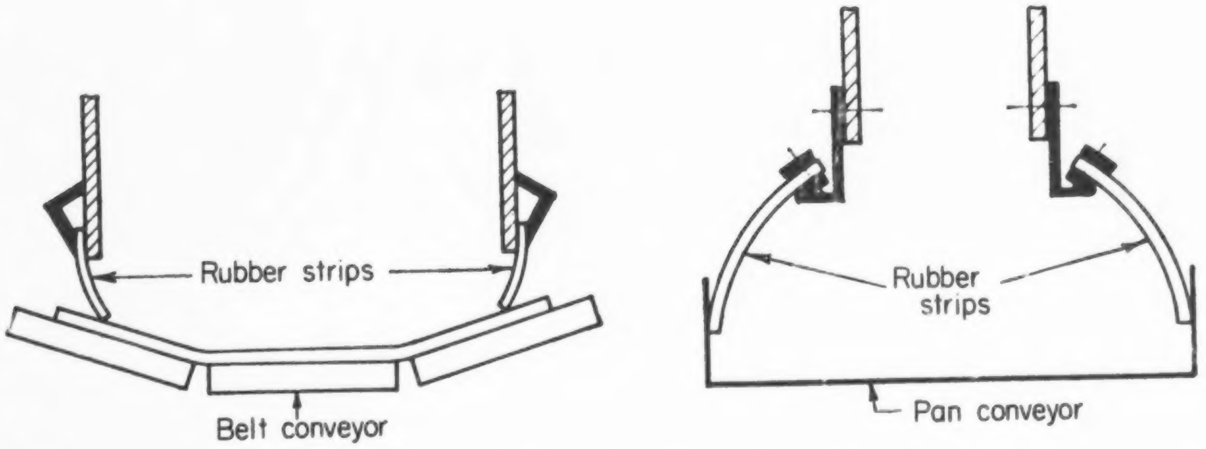

Vent
Mine car in rotary dumper
Baffle
Exhaust
Air flow
Material flow
Vent
Conveyor

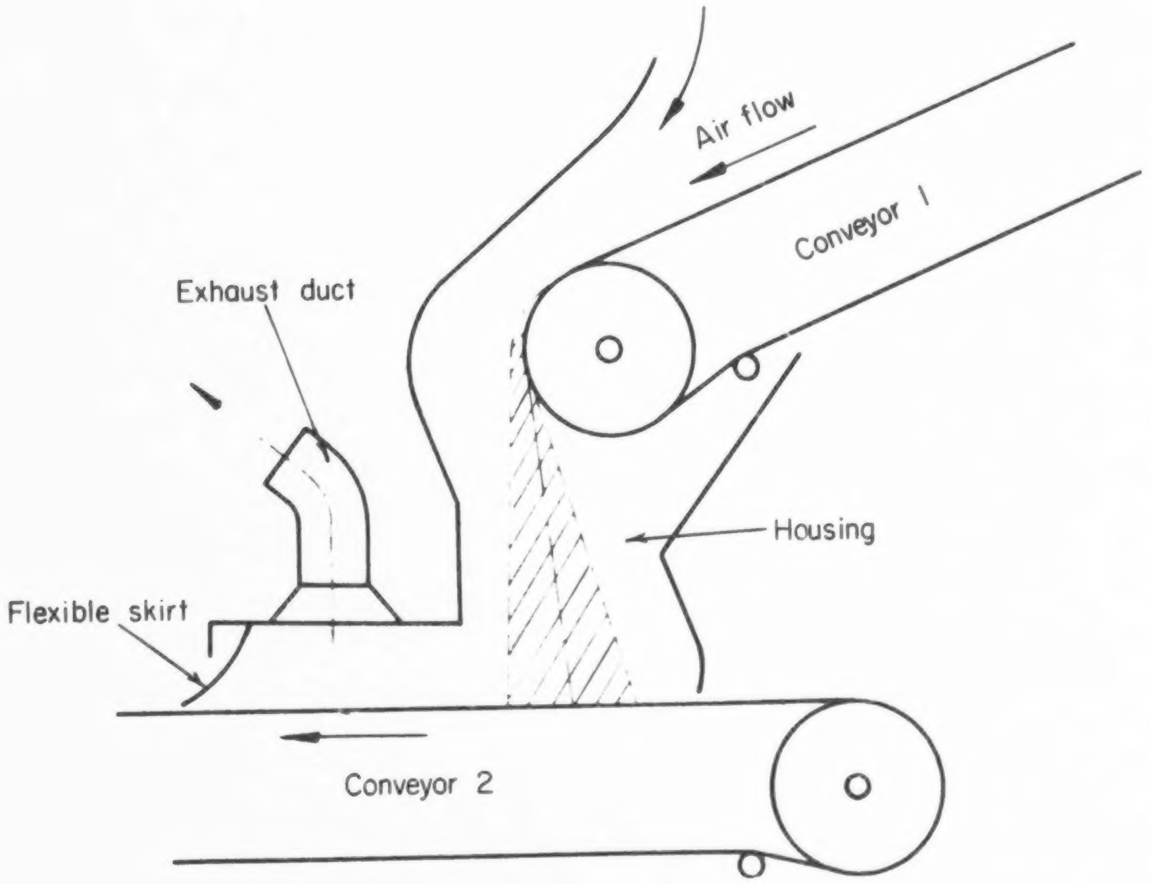
FIGURE III-4. GERMAN ARRANGEMENT OF DUST HOODS FOR A ROTARY CAR DUMPER

This design for a small (3-cubic-meter) mine car requires a draft of 50 to 60 car volumes per minute. Ends of car-dump building are configured to and blocked by ends of next and previous cars dumped.

Source: Engels, Lothar H., Op. Cit.


Rubber strips
Belt conveyor
Rubber strips
Pan conveyor

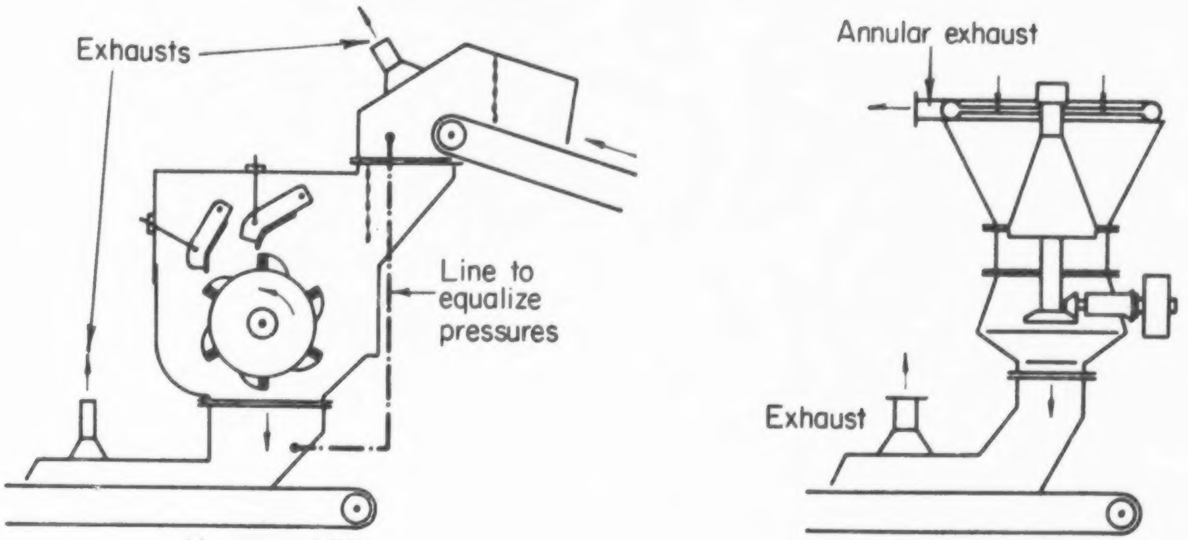
a. Illustrating Use of Rubber Strips to Seal Sides of Shroud


Air flow
Conveyor 1
Exhaust duct
Housing
Flexible skirt
Conveyor 2

b. Illustrating Arrangement of Shroud

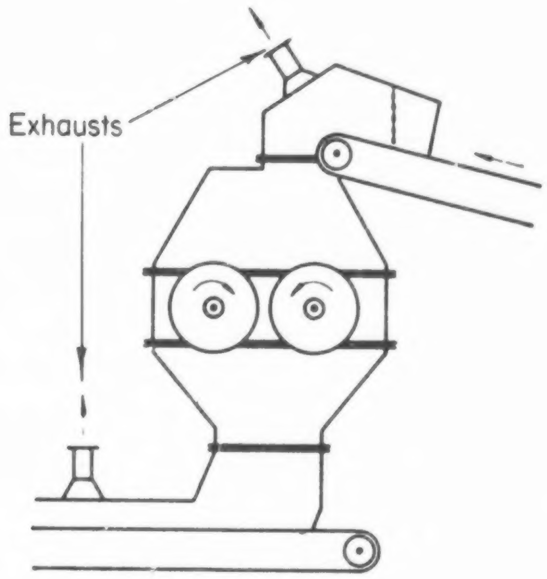
FIGURE III-5. SHROUDING AND EXHAUSTING OF BELT-TO-BELT TRANSFER POINTS (GERMAN DESIGNS)

Source: Engels, Lothar H., Op. Cit.


Exhausts
Line to equalize pressures
Annular exhaust
Exhaust

Hammer Mill

Cone Crusher



Roll Crusher

FIGURE III-6. ARRANGEMENT OF CRUSHER AND MILL DUST HOODS (GERMAN DESIGNS)

Source: Engels, Lothar H., Op. Cit.

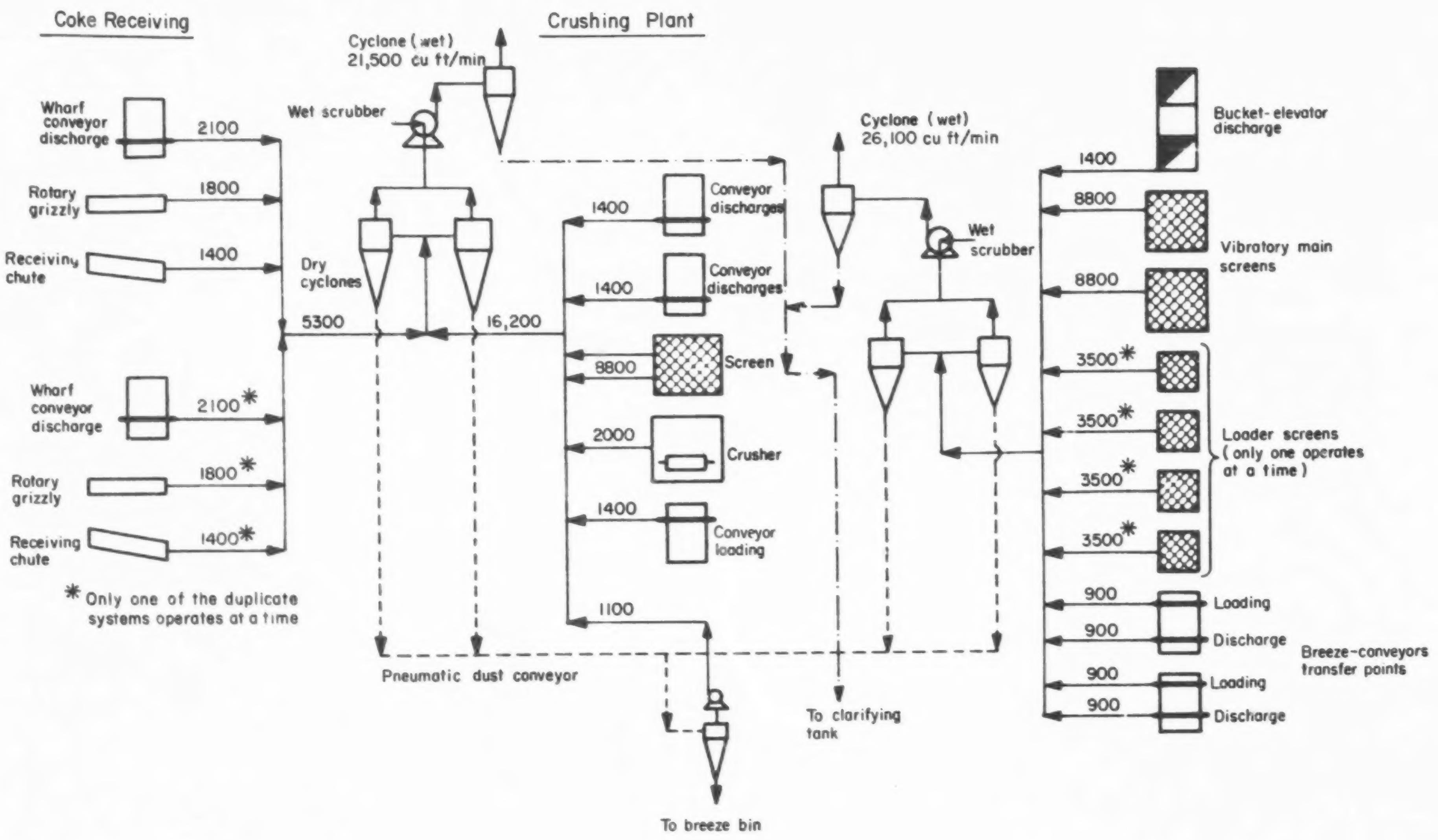

Coke Receiving
Crushing Plant
Wharf conveyor discharge
Rotary grizzly
Receiving chute
2100
1800
1400
2100*
1800*
1400*
* Only one of the duplicate systems operates at a time
Cyclone (wet) 21,500 cu ft/min
Wet scrubber
Dry cyclones
5300
16,200
Pneumatic dust conveyor
1400
Conveyor discharges
1400
Conveyor discharges
8800
Screen
2000
Crusher
1400
Conveyor loading
1100
To breeze bin
To clarifying tank
Cyclone (wet) 26,100 cu ft/min
Wet scrubber
1400
Bucket-elevator discharge
8800
8800
Vibratory main screens
3500*
3500*
3500*
3500*
Loader screens (only one operates at a time)
900
900
900
900
Loading
Discharge
Loading
Discharge
Breeze-conveyors transfer points

FIGURE III-7. EXHAUST AND DUST-REMOVAL SYSTEM FOR A COKE-SCREENING PLANT

Numbers are cubic feet of gas (air) per minute.

Source: Engels, Lothar H., Op. Cit.

Ideally, it would seem attractive to attempt complete recycling of dedusted air back into coal-handling buildings and coke-screening plants. The elimination of outside exhausts would eliminate a source of minor emissions. However, there would be practical problems in any closed system because of buildups of moisture, carbon dioxide, and stagnant air. Also, the entry and exit ports of these plants cannot be completely closed. Thus, even if dust removal is highly efficient, the air must be exhausted.

In an essentially closed building, with fresh air entering only via the materials ports and/or controlled ventilators, malfunction of dust-collecting apparatus can lead rapidly to hazardous situations. Interlocks and auxiliary power leads are needed as follows to guard against dust buildups within the closed areas:

(1) Auxiliary power connections to keep the dust system operating during unplanned shutdown of the handling machinery (as by power failure)

(2) An interlock to shut down dust-raising operations (usually the entire building) if the dust-collector malfunctions

(3) An interlock to detect loss of draft in critical ducts, and to shut down operations as required.

In the devising of interlocks, emissions control is not a direct concern in two of the three cases. The main point of this approach is that air-pollution safeguards are to be obtained by closure of the coal-handling and coke-handling systems, and all other measures taken within the enclosures are to be based on safety and hygiene considerations.

A coal-handling plant of the future, such as one that feeds a preheating and pipeline-charging system, may contain few open conveyors other than those needed to carry unprocessed coal into surge bunkers. Beyond the interim storage, coal processing (all the way to the coke ovens) may be fully enclosed in sealed ducts, and conveying systems may be based upon screws, gravity pipes, or pneumatic transfer. From one point of view, this approach to coal handling will be cleaner, but the gases (steam or combustion products) used in conveying and fluidizing must be dedusted somewhere, and some of them will have to be exhausted.

Charging of Coal to the Slot Ovens

Prepared coals, blended and adjusted for appropriate bulk density, are carried as weighed individual charges along the battery from the coal bunkers to the coke ovens in a broad-gauge, tracked vehicle with three to five hoppers. The vehicle is called a larry car. The larry-car hoppers receive weighed amounts of coal and then discharge the coal through chutes into round ports on top of an oven. After the coal has been dumped, a small "chuck door" is opened on the pusher side, and a long steel beam is pushed back and forth along the top of the coal to level it.

Apparatus and Operations

The sequence of charging and leveling was depicted schematically in Figure II-2. Larry cars do not differ much in basic design, but the discharge of coal from the hoppers has been variously regulated by screw or table feeders in some of the postwar plants. A whole new generation of larry cars equipped for dust collection and smoke control has been built in Europe, and proposed U. S. solutions to smoke emissions variously either include a sophisticated highly mechanized larry car or involve elimination of the larry car.

The emissions accompanying charging of coke ovens arise because of three factors:

(1) The entering coal rapidly displaces about 90 percent of the free space in the oven, and the displaced air may leave through four to six ports, only one (rarely two) of which is not open to the atmosphere.

(2) The moisture in the coal is immediately put into contact with the incandescent oven walls and floor, and much of it is flash-vaporized. Whereas 50 pounds of coal charged will occupy 1 cubic foot, loss of 0.1 percent (0.05 pound) moisture from this coal by flash evaporation will displace an additional 1.7+ cubic feet at 500 F.

(3) The coal itself is susceptible to thermochemical breakdown as soon as it has become heated to over 500 F; and smoke, tar vapors, and gases are formed by these pyrolysis reactions.

The usual result is that steam, gas, and displaced air blow (in the form of clouds of smoke, fume, and dust) out of the oven ports during charging. These emissions are highly visible, and some of the substances released may be noxious.

Table III-1 lists a typical sequence of charging operations in more detail, and indicates usual periods of emission. Figure III-8 shows activities and job assignments in a time frame for a similar British practice.

Emissions

Coal consists primarily of high-molecular-weight aromatic hydrocarbons of the benzene family. Under the conditions of charging, some of these hydrocarbons are directly vaporized (anthracene, chrysene, phenanthrene, and naphthalene). Some break down to yield methane and lighter aromatics such as benzene. Some give off their hydrogen and are rapidly coked to graphite. One form of emission that has been studied and attributed to charging is the "coke ball" - a small, porous globule of coke carbon, apparently formed upon the rapid decomposition of a tar droplet (or coal particle fused to form tar) in the charging gases. Figure III-9 illustrates a coke ball found in the vicinity of an Eastern coke plant.(3) Char and pyrolytic carbon are also components of the charging smoke, as is unaltered coal dust. It may be presumed that most of the oxygen in the air displaced from the oven is destroyed by combustion reactions. The gases will contain some nitrogen, carbon monoxide, carbon dioxide, hydrogen, methane, and steam.

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(3) Herrick, R. A., and Benedict, L. G., "A Microscopic Classification of Settled Particulates Found in the Vicinity of a Coke-Making Operation", Paper No. 68-137, Air Pollution Control Association.

TABLE III-1. SEQUENCE OF CHARGING OPERATIONS

Elapsed time[a], minutes	Operations	Emissions
0.0	Larry car is filled at blended-coal bunker and weighed. Oven doors are replaced. If lids of charging ports are removed by hand, this is done now.	Dust at bunker discharge.
2.0	Larry car moves to position over the charging ports. (Automatic lid lifters, if provided, lift lids.) Drop sleeves are lowered into ports.	Generally none.
2.7	Steam ejector in standpipe is turned on to draft oven. Coal begins to flow from hoppers on larry car and first rush of gases ignites within the oven.	Smoke emission begins slowly at ports.
2.8	Heavy rush of smoke, dust, and gas emerges around charging ports as steam formation increases oven pressures rapidly. Hoppers continue to discharge.	Brown to black smoke, with some flashes of flame.
4.0	Hoppers discharge more slowly as coal in oven rises to bases of the charging sleeves. Pusher operator goes to open the chuck door for leveling.	Continued smoke.
5.0	Coal discharge completed, drop sleeves raised. On signal from larryman, leveler bar is pushed all the way across oven, then cycled back and forth 3 to 5 feet to level the coal.	Smoke continues from ports and from the chuck door.
5.7	After 5 to 7 strokes of the leveler bar, it is withdrawn. Larryman operates lid-replacement system, or if none, he moves the larry car and crew begins to replace the lids by hand. Chuck door is closed and ejector is turned off.	Smoke continues until chuck door and port lids are well seated.
6.5	Charging completed.	Smoke via leakage only.

(a) Attainable with mainly hand operations if coordination between larryman, top crew, and pusherman is good. Charging of tall ovens or with sequenced discharge of hoppers may take longer, and some time is generally wasted between steps.

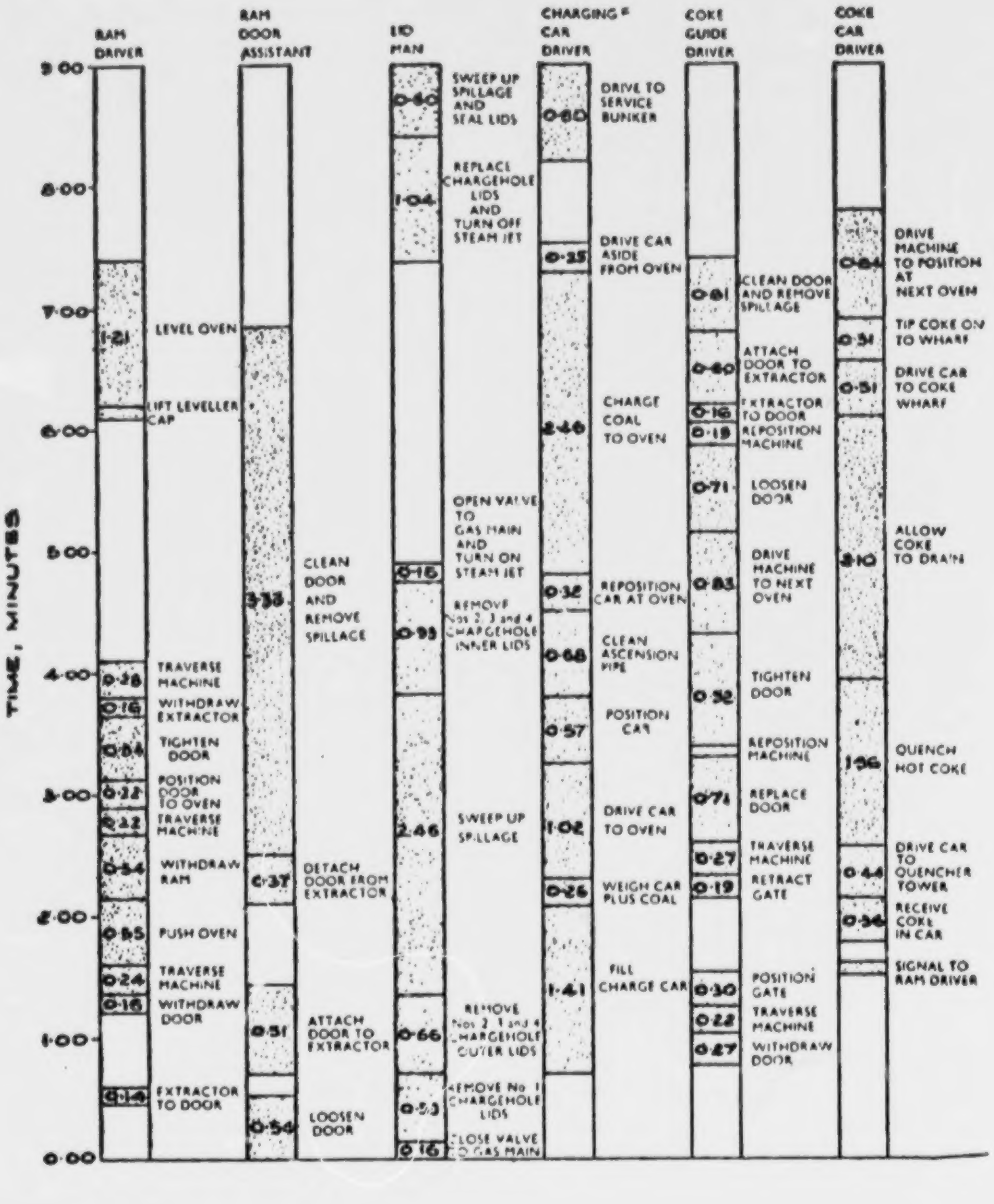

FIGURE III-8. OPERATIONS, JOB ASSIGNMENTS, AND TIMING FOR A PUSHING AND CHARGING OPERATION IN THE UNITED KINGDOM

Source: Sellars, J. H., and Hornsby-Smith, M. P., "Studies of Smoke Emissions During the Charging of Coke Ovens", The Coke Oven Managers' Year-Book, 1961, pp 212-237

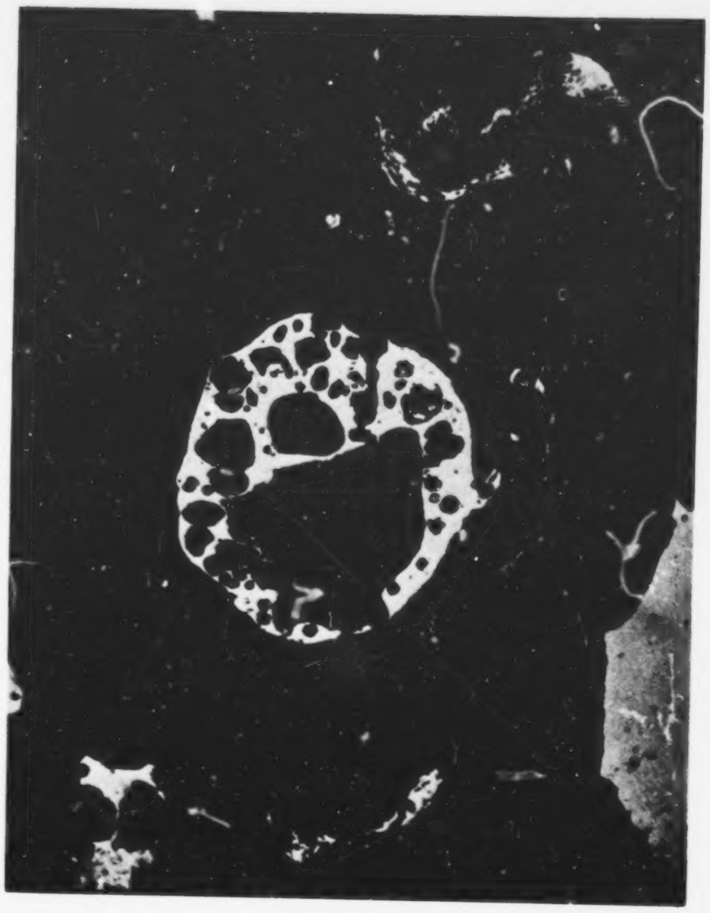

FIGURE III-9. A COKE BALL AS FOUND BY HERRICK AND BENEDICT

Source: Herrick, R. A., and Benedict, L. G., Op. Cit., "A Microscopic Classification of Settled Particulates Found in the Vicinity of a Coke-Making Operation".

Several investigators have reported the presence of suspected carcinogenic tarry hydrocarbons in coke-oven smoke. These materials, known as the polycyclic (or polynuclear) aromatic hydrocarbons, are suspected carcinogens because of their action on mice and because of alleged high incidence of cancer among men who work with pitch and carbon black. Prominent among these materials is 3, 4-benzpyrene, also known as benzo-a-pyrene. Although these compounds are noxious, they are also transient, easily destroyed, and possibly self-canceling.(4) The American Conference of Government Industrial Hygienists has established a threshold limit value of 200 micrograms per cubic meter for coal-tar pitch volatiles.

Measurements of emissions of charging smoke have been reported for some European coke plants, but the data show a tremendous range and probably do not represent U. S. conditions. The range of reported dust losses was from a minimum of 41 to a maximum of 1250 grams per ton of coal, and the range of hydrocarbons released was reported to be from 57 to 800 grams per ton of coal.(1) No dependable authoritative estimates for U. S. conditions have been located.

North American sources among coke-oven builders and operators say that charging emissions are much greater under U. S. conditions because the coals are higher in volatile content, the oven walls are hotter, the moisture content of coal is lower (and thus more easily flashed), and charging rates are faster. Although this is undoubtedly correct for comparison with Continental Europe and for the practices of several years ago, British coke plants now use coals with volatile content higher than or equal to ours, and U. S. coals are getting wetter as a result of more thorough beneficiation and finer shipped sizes.

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(4) Boyland, E., "Polycyclic Hydrocarbons", British Medical Bulletin, 20 (2), 121-126 (1964).

Alleviation

Several new practices, systems, and devices which are intended to control or prevent oven-charging emissions are being developed and competitively promoted in Europe and North America. Because one or two of these systems is likely to dominate in terms of cost, effectiveness, and reliability, the competitive pressures are high at this time.

Charging on the Main. The traditional approach to alleviation of charging smoke has been to draw it off into the collector main, and thence into the by-products system. This practice, known as charging "on the main", is based upon use of a steam ejector to produce a draft in the ovens during charging. The steam ejector typically is located at the top of the ascension pipe, as shown in Figure III-10. It is operated during charging, and sometimes for a few minutes after charging has been completed. Some of the principal innovations tried to improve the effectiveness of so-called smokeless charging include (1) use of twin collector mains, one at each side of the battery; (2) use of a "breeches pipe" to connect the other end of the oven with the end served by the steam ejector; (3) relief of the bottoms of the charging ports into conical shape to minimize blockage of the gas space by piled coal; and (4) sequential charging from the larry-car hoppers so that the free space for gases is kept open as long as possible. All of these innovations have been more or less successful, but most of them involve one or more problems or extra expenses. The defects appear to be as follows:

(1) Twin collector mains are costly, and they tend to block ventilation of the oven top so that heat is trapped, working conditions become worse, and less smoke makes more nuisance in the immediate area.

(2) Breeches pipes may require extra handling operations, extra ports, and extra maintenance out of proportion to their effect.

(3) Conical relief of the bottoms of charging ports is not practical with some oven designs involving crossover flues, and the flow of gas through the cone area (in the presence of a partly open port just above) is inefficient.

(4) Sequential charging is electromechanically complex, such that it may fail through lack of maintenance attention.

Charging on the main is generally ineffective if judged by expected future air-quality criteria because a draft strong enough to eliminate smoking from the most distant charging port will likely be too strong for the closer ports, such that too much air is drawn into the oven. This air will react with organic materials in the gas and smoke, so that chemical values are lost and additional but weaker gas is produced. A very strong draft in the presence of partly open ports would produce a strong internal fire,

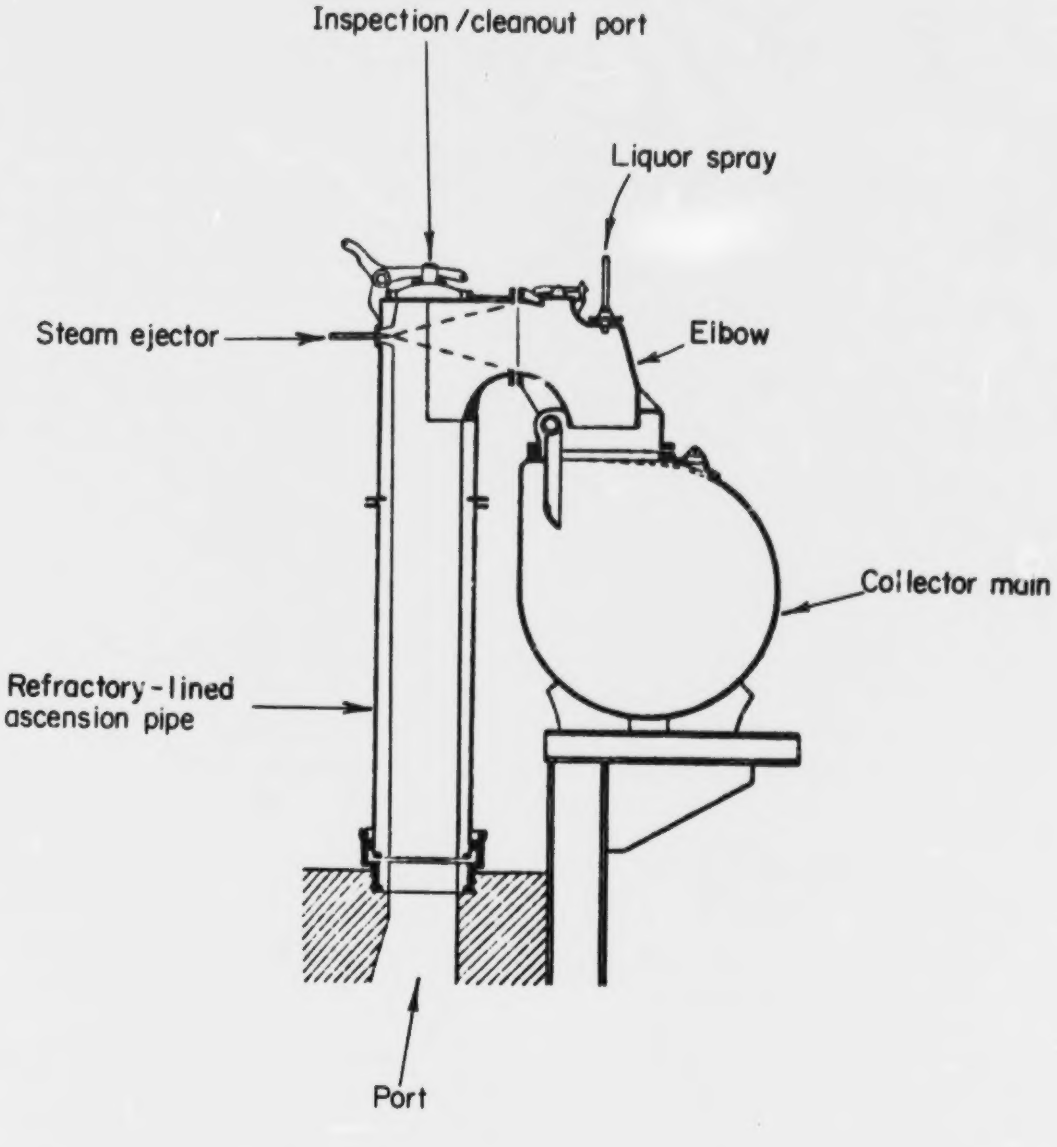
Inspection/cleanout port
Liquor spray
Steam ejector
Elbow
Collector main
Refractory-lined ascension pipe
Port

FIGURE III-10. TYPICAL ARRANGEMENT OF THE ASCENSION PIPE, ELBOW, AND COLLECTOR MAIN

Source: Freihmelt, E., Lüpke, H., and Ruschmann, W., "Betriebliche Erfahrungen mit der Füllgasabsaugung bei Koksöfen", Gas - u. Wasserfach, 101 (43), 1109-15 (October, 1960) and perhaps explosive effects if ignition were by chance delayed. Accordingly, present practices for charging on the main are intended only to alleviate the rush of smoke, not to prevent smoking entirely. The results usually are so unsatisfactory that better controls are being sought by the steel industry.

Charging on the Main With Closed Coal Ports. One of the three prominent modern approaches to improved control of the charging smoke is actually an updating and re-engineering of charging of the main. This approach, which is designated for this report as charging on the main with closed coal ports, is a development by Firma Carl Still of Recklinghausen, in the Ruhr District (Rheinland-Westphalia) of West Germany. A similar concept is also under development (with special undisclosed differences for United States conditions) by the Joint Coordinating Committee on Coke Plant Equipment, a task force organized by the American Iron and Steel Institute. With Jones and Laughlin Steel Corporation as Project Manager, the Joint Coordinating Committee has retained Koppers Company of Pittsburgh to design, build, and test components of a new system that also employs closed coal ports.

Inasmuch as all descriptive detail obtained for charging on the main with closed ports was furnished by Firma Carl Still, the version described in this report is drawn from their comments and their patent applications as filed. Accordingly, this description is not to be taken as representing the "AISI" system, which may differ in some major concepts and/or in mechanical details. On the other hand, use of information from patent applications or texts anywhere in this report should not be construed as a validation of the claims made.

For the Still version of charging on the main with sealed ports, the following description is taken from United States Patent Application Serial 810,588 as translated and paraphrased by Battelle from a German text. The German filing date was March 26, 1968, and the U. S. filing date was March 26, 1969:

> Coke ovens can be charged without emissions if one employs a charging procedure with the following measures:
>
> I. The charging of coke ovens is undertaken by adhering to charging times of perhaps 2 to 6 seconds per ton of coal;
>
> (a) When drawing off the coal into the oven, some coal is left in the charging hoppers or in their discharge chutes to seal off the gases from the atmosphere.
>
> (b) The larry car is driven into position over the charging ports to be used, and the charging-port lids are pulled off and swung to one side. The coal discharge chutes are lowered and set upon the charging-port seats. The hoppers are then emptied into the oven chamber, and the discharge chutes are pulled away individually in the same sequence as the emptying of the hoppers. The charging-port lids are swung back again and set onto the charging-port seats, so that in each case air can flow through one open charge port into the oven for only a short time.
>
> (c) The lowerable coal discharge chutes of the charging hoppers are mounted relative to the hoppers, and are horizontally adjustable in all directions.
>
> II. A sealed leveler bar is used.

III. In the ascension pipes of the coke ovens being charged, a steady negative pressure of from 2 to 6 millimeters water column is created by steam jets when the leveler bar casing has been set in front of the chuck door and closed by the leveler bar.

It has turned out that if the charging-port seats and discharge-chute seals are kept clean, and the sealing surfaces are set up with adequate care, then with the combination of features of the invention, such a pressure is sufficient for reliably preventing the escape of emissions and for reliably avoiding burdening of the condensates with solids and dirtying of the gas-treatment installations. Up until now, it was not known that the relatively low negative pressure would be adequate. It turned out that in comparison with known charging methods there is a 1 to 1.5 percent higher yield of coke-oven gas.

In German Patent Application G 36 944 VIb/loa, there has been suggested a larry car with suitable charging chutes under the hoppers, appropriate to the charging method of this invention. The coal discharge chutes of the hoppers on this car hang from double hangers; they set down perpendicularly and tight upon the charging-port seats, even if the axes of the ports and hoppers are not identical.

For leveling, a bar is used which consists of two side-beams with connecting crossbars. The leveling bar is surrounded by a sealing shoe. On the inside, the shoe is fitted for better sealing-off, and is synchronized with the distance between the leveler crossbars, so that at least one crossbar is always in the shoe.

The continual drawing off of the charging gases is guaranteed by the fact that leveling is started when roughly two thirds of the coal has been charged into the oven. The hoppers are unloaded in a sequence so that no stopping-up of the gas occurs. For example, first the two outer hoppers are discharged, then the neighboring ones on each side, and finally the central hopper.

A leveler rod without a shoe may be used. For this purpose the chuck door is quickly opened by machine. Directly after this, the leveler bar is inserted, so that air streams into the oven from the chuck door for only a short time.

The opening of the chuck door takes place, for example, by a car mounted on the leveler machine. The car opens the chuck door by means of a rod arrangement.

Still's drawings filed with this description, simplified and annotated by Battelle, are presented in Figures III-11, III-12, and III-13. They show, respectively, an elevation of the larry car with the coal-discharge chutes in various positions depicting stages of the charging cycle; a top view of the mechanism for automatically opening and closing the chuck door; and a side section view of the sealing shoe and leveling bar.

The Still version of charging on the main with sealed ports is more complicated than normal charging, especially as regards the timing and sequencing of operations. The present equipment built by Still must be located over the charging ports to within a 30-millimeter (1-1/4-inch) tolerance in all directions for all ports simultaneously. The system requires automatic lid lifting and replacement, automatic detection of coal level when the hoppers become nearly emptied, automatic sequenced charging, and automatic regulation of the pressure differential between the oven and the atmosphere. The leveling operation must be coordinated with chuck-door opening and closing, and also with the filling sequence. To the extent that seals, sequencing, or pressure controls are out of balance with fixed requirements, it is possible to have either emissions, or excessive dust carryover, or both. The principal criticism offered for this approach is that it may require more individual functions and more precise coordination of functions and apparatus than can readily be provided on a continuing, reliable basis.

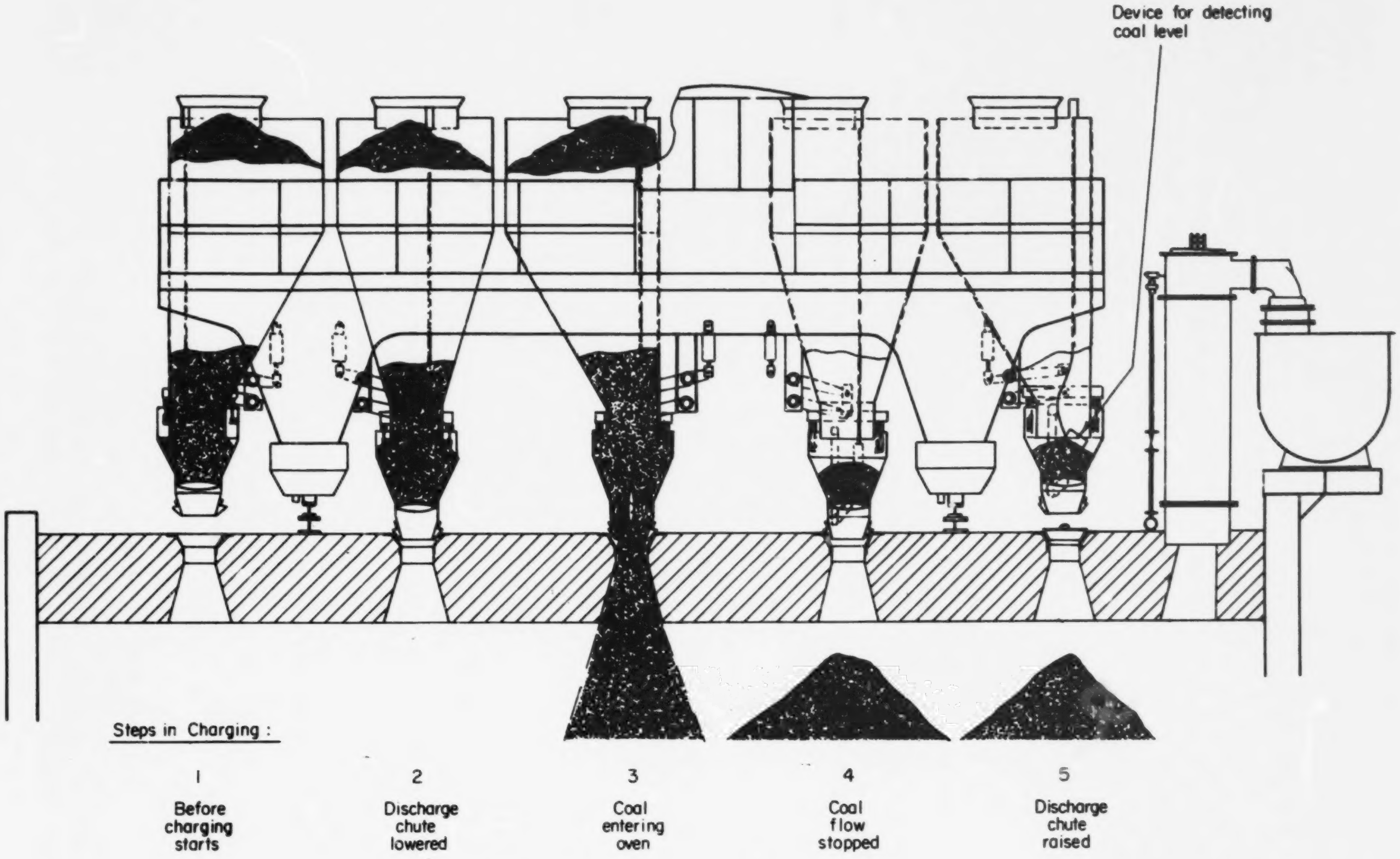
Device for detecting coal level
Steps in Charging :
1
Before charging starts
2
Discharge chute lowered
3
Coal entering oven
4
Coal flow stopped
5
Discharge chute raised

FIGURE III-11. ELEVATION OF FIRMA CARL STILL CLOSED-PORT LARRY CAR SHOWING STEPS IN CHARGING

Source: U. S. Patent Application Serial 810, 588 by Firma Carl Still

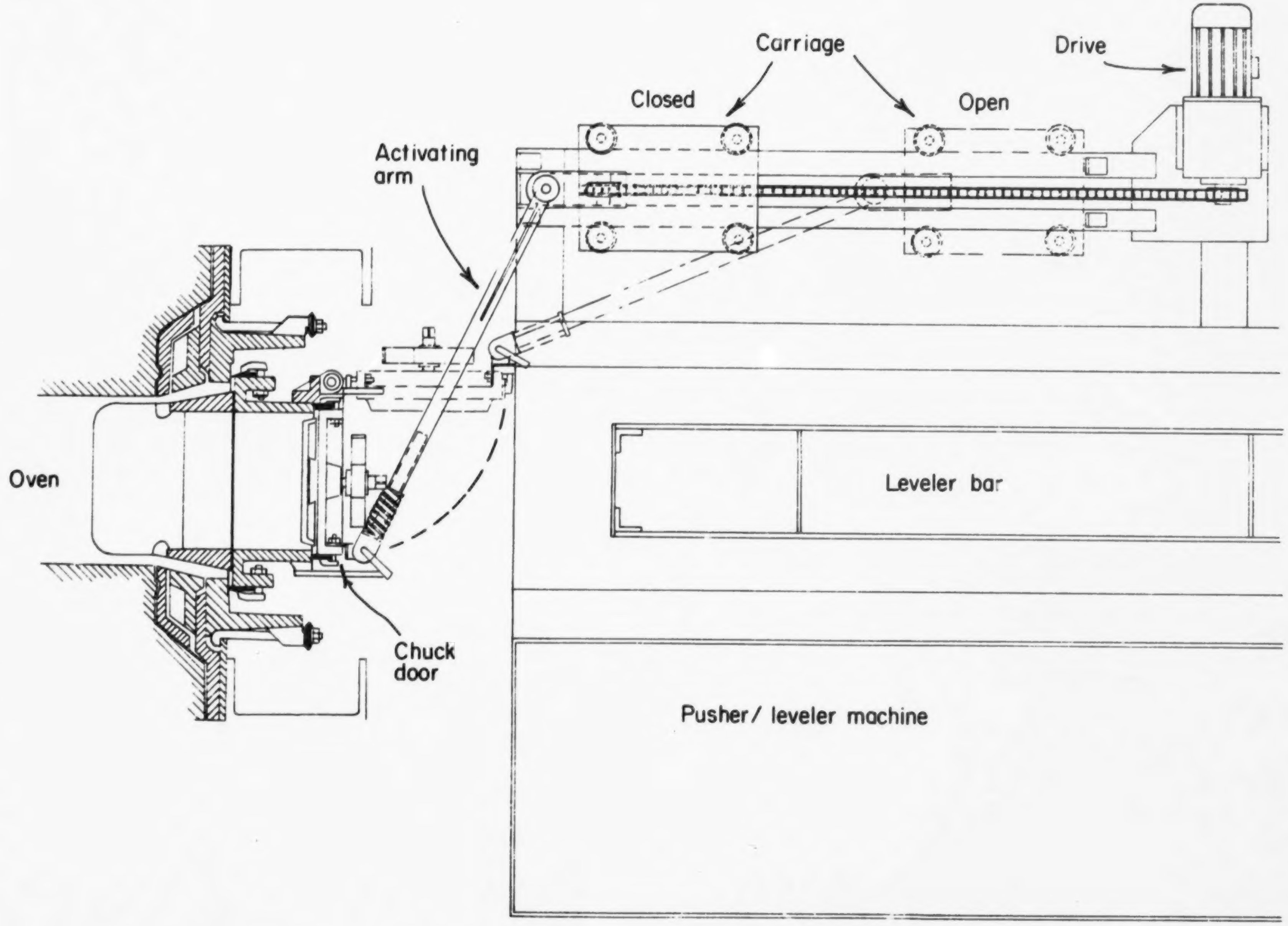
Carriage
Drive
Closed
Open
Activating arm
Oven
Leveler bar
Chuck door
Pusher/ leveler machine

FIGURE III-12. TOP SECTIONAL VIEW OF MECHANISM FOR AUTOMATIC OPENING AND CLOSING OF THE CHUCK DOOR

Source: U. S. Patent Application Serial 810, 588 by Firma Carl Still

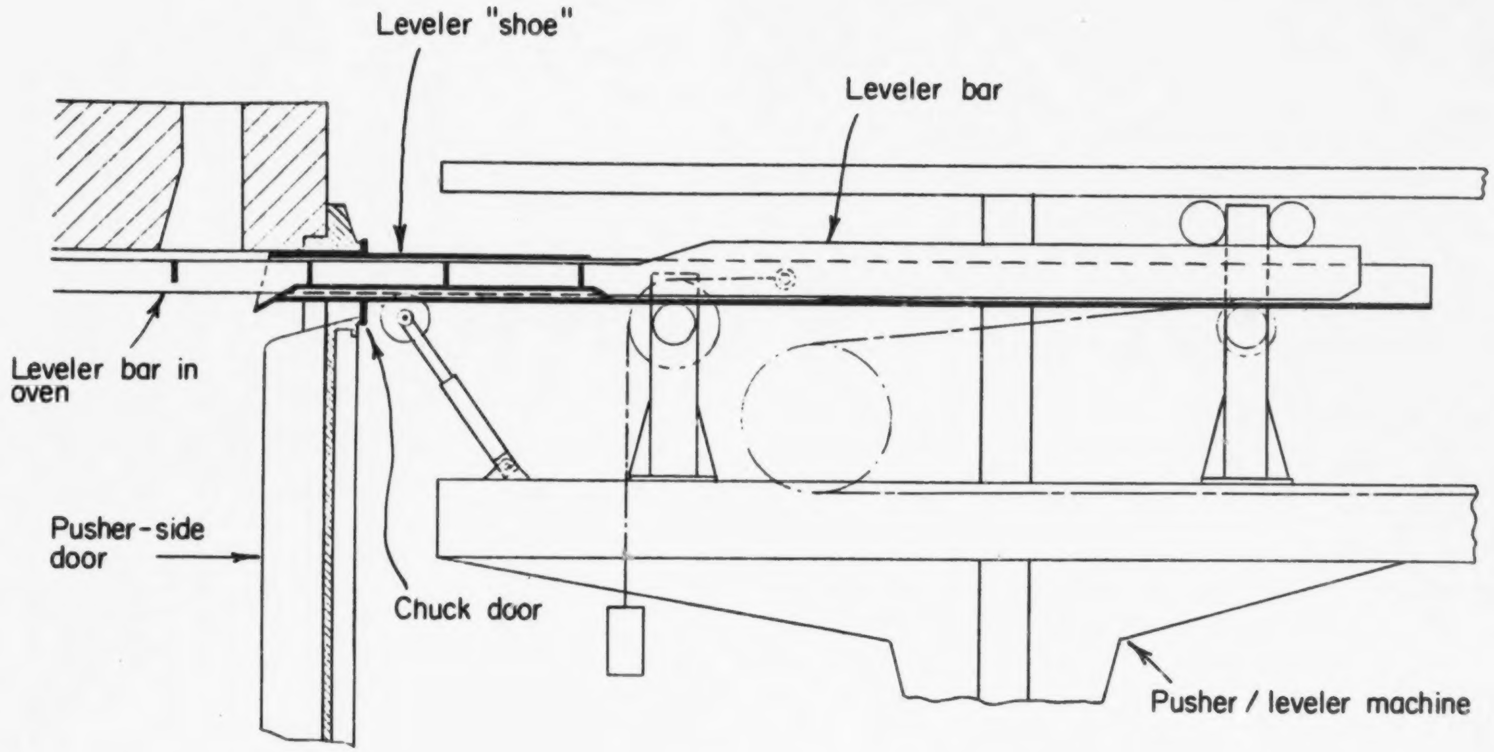
Leveler "shoe"
Leveler bar
Leveler bar in oven
Pusher-side door
Chuck door
Pusher / leveler machine

FIGURE III-13. VERTICAL SECTION VIEW OF SEALING SHOE FITTED TO CHUCK DOOR AND LEVELER BAR

Source: U. S. Patent Application Serial 810,588 by Firma Carl Still

One source told Battelle that certain European plants using the Still type of charging control have become involved in frequent cleanouts of the tar decanters owing to difficulty in managing coal-dust carryover. This was not specifically confirmed. The work being done by the AISI team on similar charging controls is known to emphasize two critical points: (1) provision for automatic cleaning (or for prevention of tar buildups) in the ascension pipes and elbows, and (2) provision for fully automatic sequencing of all operations and controls. A later Still patent application, filed in the United States on July 18, 1969, provides flexible-hose couplings between the several coal-discharge chutes and, if necessary, between the nearest discharge chute and the ascension pipe, so that draft can be maintained in all parts of the system if the free space becomes blocked with coal. This hose has loops so that it will clear itself of coal.

The Still system as used in Germany and Italy has been installed on seven larry cars. Although the concept of charging on the main with closed ports is being developed for trial in the United States, the Still version of this concept will not be the first one used. The involvement of the American steel industry through the AISI virtually assures that the AISI version of charging on the main with sealed ports will be demonstrated first. Battelle is not in a position to review the specific merits of the U. S. version except upon presumption of similarities to the Still version.

Pipeline Charging. The second of three principal systems being readied for full-scale trial in the United States is pipeline charging of coal via pneumatic (airless) means. No larry car is involved. The system is a proprietary development of the Allied Chemical Corporation, builders of Wilputte-type coke ovens. Descriptive information about this concept and apparatus has been drawn, at Allied's suggestion, from four United States patents granted between March, 1968, and July, 1969.(5) Allied personnel stated that the system actually being installed for full-scale trial may contain any of the many variants explained, plus new ideas not yet disclosed. The following description is taken from the Allied patents, as paraphrased by Battelle:

> The advantages of introducing coal preheated to a temperature within the range of from 250 to 700 F has been recognized. Paramount among these advantages is the reduction of coking times with consequent increase in the capacity of the battery. When coal containing moisture is introduced into the coking chambers, about 40 percent of the total coking time is spent to evaporate water and to raise the temperature to the range of from 250 to 700 F. In modern practice the coking time is usually from about 15 to 30 hours. A saving of 40 percent of this time is indeed important. The charging of preheated coal also improves the quality of the coke, especially in the case of coals with higher oxygen content, such as Illinois coals.
>
> The introduction of preheated coal employing a conventional larry, involving the dumping of the charge into the coking chamber in about one or two minutes, has the serious objection that the hot coal may catch fire. Such rapid charging has the further disadvantage of introducing excessive suspended particles in the raw gas.
>
> The problems involved in effecting feed of the preheated coal from the preheater into the coking chambers are indeed manifold. Necessary precautions must be observed to prevent hot coal particles from catching fire. Ordinary pneumatic transport employing air as the carrier gas is out of the question. The feed of the hot coal must (a) be smooth, (b) be reasonably rapid, (c) be under conditions

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(5) The basic patents are U. S. Patents Numbers 3,457,141; 3,438,867; 3,374,151; and 3,381,901.

avoiding excessive carryover of fine particles, (d) avoid a smoke nuisance, and (e) not interfere with the collection of coke-oven gas from other coking chambers.

It is a principal object of the present invention to provide a novel procedure of charging the coke chambers of coke-oven batteries with coarsely comminuted, preheated coal particles so as to effect such charging smoothly and efficiently.

In the preferred embodiment, transporting from one to three tons of preheated coal per minute through a pipeline of 6-inch diameter, the coal and superheated steam at a pressure of preferably 5 to 30 psig are first introduced into the upstream end of the pipeline. The velocity of the steam and preheated coal mixture within the pipeline is from 10 to 200 feet per second. Steam jets for impelling and dispersing the coal are positioned in the bottom of the pipeline at an angle of from 5 degrees to 20 degrees to the horizontal and in the desired direction of flow of the preheated coal. Steam is supplied to these jets at pressures ranging from 25 to 600 psig. Along the length of the pipeline, the spacing of these jets is preferably 12 to 18 inches apart. The jets are spaced somewhat closer in the bends, e.g., every 5 degrees to 9 degrees of arc. A larger radius of curvature permits larger spacing of the jets.

In each jet the steam expands to preferably supersonic velocity, and thus imparts pulse to the coal particles, thus aiding the flow. Relatively low-pressure conditions are maintained throughout the pipeline within the range of from 0 to 50 psig and at velocities which do not exceed about 200 feet per second. The introduction of superheated steam through jets avoids the necessity of excessively high pressures at the entry to the pipeline.

The rate of flow of unscreened hammer-milled coal through a horizontal pipeline 6 inches in diameter and 130 feet long, equipped with jet plugs spaced 8 inches apart, is given by the following empirical relationship:

$$R = 0.5 + 0.5\sqrt{P} \quad ,$$

wherein

R = rate of flow of coal in tons per minute

P = pressure in psig in the measuring bin supplying the hot coal to the feed end of the pipeline.

Good transport is obtained when the ratio of preheated coal to steam at the inlet end of the pipeline is preferably about 80; in the pipeline, up to the discharge point, preferably about 60; and upon discharge, preferably about 80.

Complete charging of the oven chamber is accomplished by imparting to the mixture of coal and carrier gas at the point of introduction a velocity adequate to distribute the coal through the length of the coking chamber.

Preferably, during charging the pressure of the steam at the end of the chamber where the preheated coal enters is limited to the range of 1/2 to 2 psig. The opposite end of the coking chamber can be vented to the collector main or to an adjacent coking chamber to insure that the pressure at that end is less. In the case of new batteries, which can be built without charging holes in the roof and which have only one collector main at the opposite side from the coal inlets, such differential pressure can be created by not venting during charging, and letting the pressure build up to the desired extent. Existing batteries require the sealing of the charging holes to prevent leakage of gas. Differential pressure within the coking chamber tends to effect the distribution of the charge, and gives a charge which does not require leveling.

Figures III-14 and III-15, respectively, illustrate the arrangements for pipeline charging overall and in section. Figure III-16 shows a cross section of the steam-jet fixture that allows Allied to move coal through a simple pipeline at low pressure and controlled velocity. Preheating systems shown in the various patents include a Herreshoff furnace, a staged counterflow dryer-heater, and a raker-hearth furnace. However, it is expected that Allied may adopt fluidized-bed preheating embodying a mill at the base of the fluidized bed, such as the one described by M. Foch of Charbonnages de France:(6)

> "It is known that the simultaneous operations of grinding, sorting, and when so required, drying of nonagglutinant materials can readily be carried out in fluidization reactor, comprising a percussion grinder, for example of the squirrel-cage disintegrator type, immersed partly or wholly in a fluidized layer of the material to be treated.
>
> "The improved device in accordance with the invention comprises essentially a fluidization chamber, at the base of which a closed conduit opens vertically, this conduit being transversed from the bottom to the top by the hot gases conveying the material to be treated, and percussion grinding means of the squirrel-cage disintegrator type, and is essentially characterized in that the moving system of the grinder is constituted by a plurality of rotating cages with bars mounted side by side on the same driving shaft and separated from each other by a free space."

The squirrel-cage mill is depicted in cross section in Figure III-17. From the standpoint of air pollution, specific arrangements for preheating of the coal are not as significant as arrangements for assuring charging in a closed, emissions-free system. This notwithstanding, much of the driving force behind the development of the Allied system is obtained from the potential productivity gains inherent in preheating. Pipeline charging, although quite attractive in its effect on emissions, was developed originally as a means of conveying hot coal into the ovens without exposing it to air. Nowhere in the patent texts is a reduction in air pollution cited as a primary advantage.

A reservation about pipeline charging is similar to one about the Still charging system: Where is the coal dust to be accommodated or disentrained? Allied has stated that this problem is solved to their satisfaction. One recent Allied patent illustrates the use of jumper pipes to distribute surplus steam and coal dust across adjacent ovens, with potential for bleed-off of some steam in each stage. Disentrainment results from heating of the coal dust in the hotter ovens to its fluid, sticky state. Successive passes through one, two, or more ovens may be used as determined by the amount of dust present. Figure III-18 shows Allied's sketch of their jumper-pipe system.

Allied reports that a new preheating and pipeline-charging system is on order for installation at a 24-oven battery in the Ironton, Ohio, plant of Allied's Semet-Solvay Division. This will be the first whole-battery installation, but not the first full-scale trial by Allied. Start-up of the new equipment at Ironton is expected in the latter half of 1970.

Direct Collection and Wet Scrubbing. The third of the three principal systems for control of charging smoke, and presently the most widely applied, seems to have German antecedents. Unlike both of the other systems, which seek to exhaust smoke into the by-product system, direct collection involves an external draft to suck the smoke into special shrouds around the coal-charging ports. In these shrouds, the combustibles

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(6) U. S. Patent No. 3,381,901.

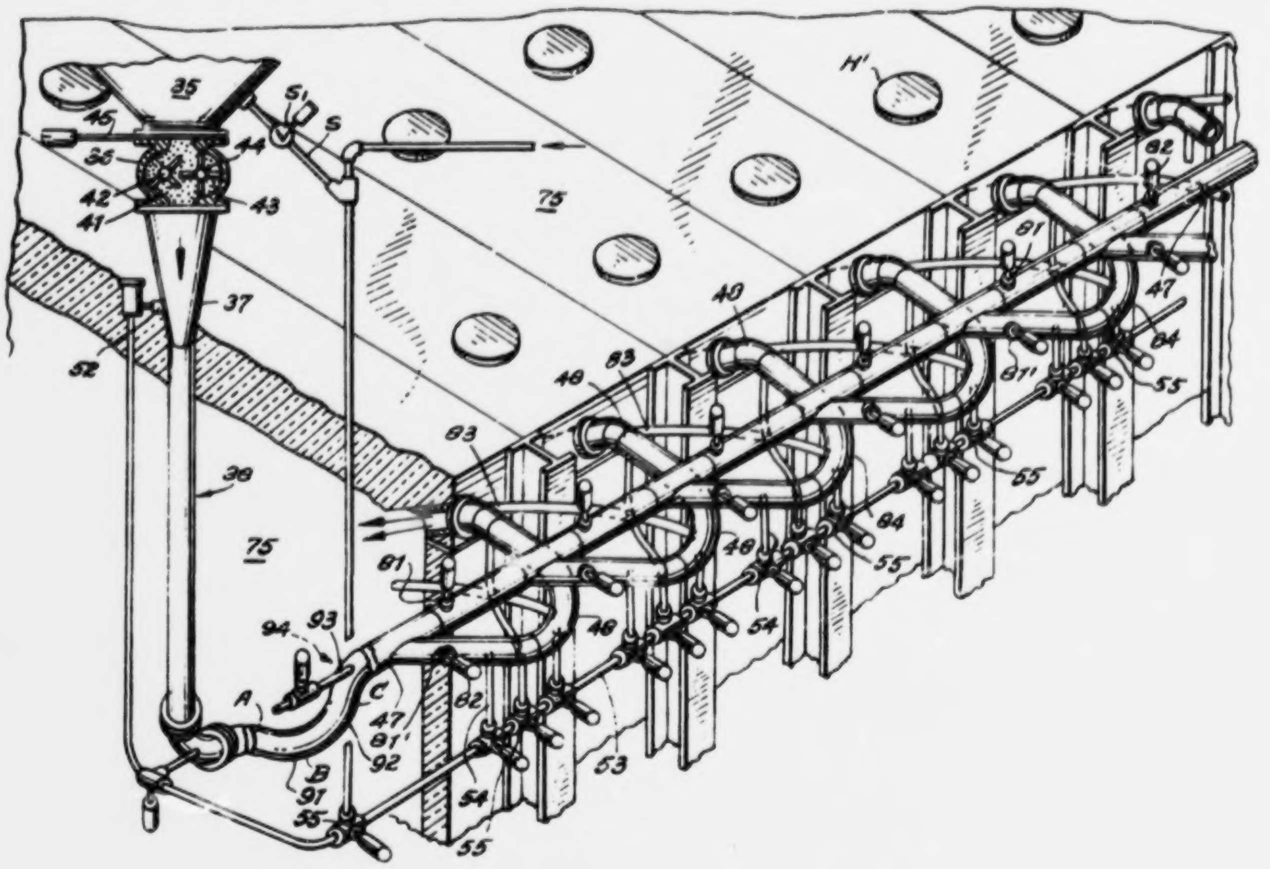

35
45
36
44
42
41
43
S'
S
75
H'
82
37
52
38
75
81
47
84
55
48
83
40
81'
65
46
54
94
93
A
C
47
81'
92
B
91
55
62
53
54
55

FIGURE III-14. GENERAL VIEW OF ARRANGEMENTS FOR PIPELINE CHARGING OF COAL

Source: U. S. Patent No. 3,457,141

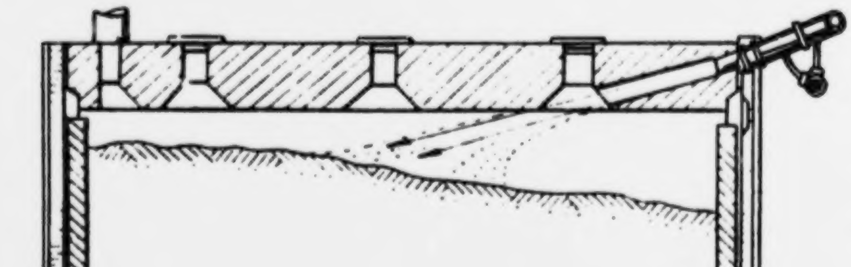


FIGURE III-15. SECTIONAL ELEVATION OF A COKE OVEN BEING CHARGED PNEUMATICALLY

Source: U. S. Patent No. 3,457,141

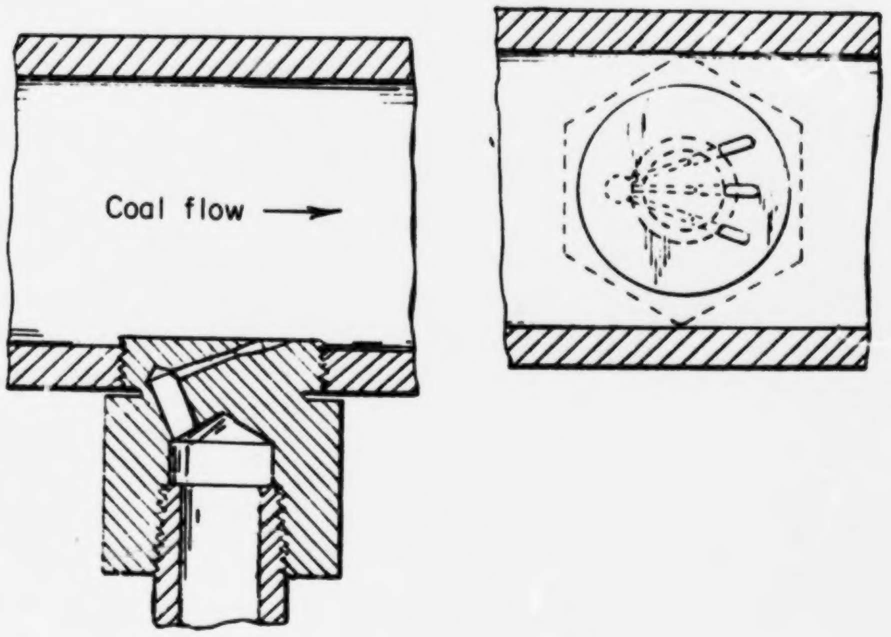


FIGURE III-16. SECTION AND VIEW OF A STEAM JET FOR MOVING COAL THROUGH A PIPELINE

Source: U. S. Patent No. 3,374,151

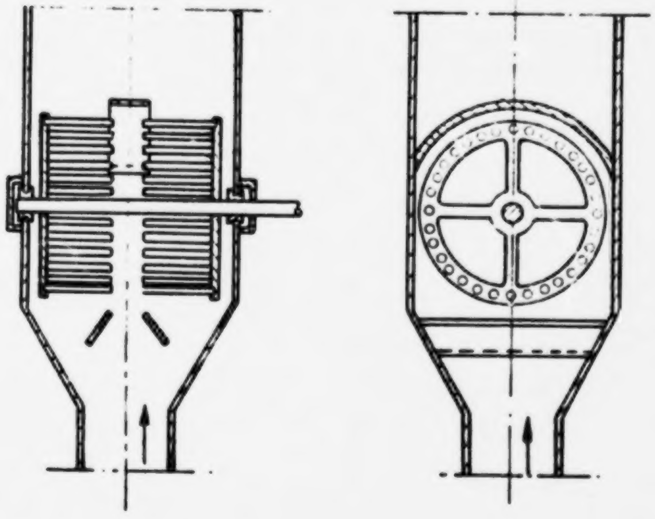


FIGURE III-17. SECTIONAL VIEWS OF A FLUIDIZED-BED SYSTEM INCORPORATING A SQUIRREL-CAGE MILL IN ITS BASE

Source: U. S. Patent No. 3,381,901

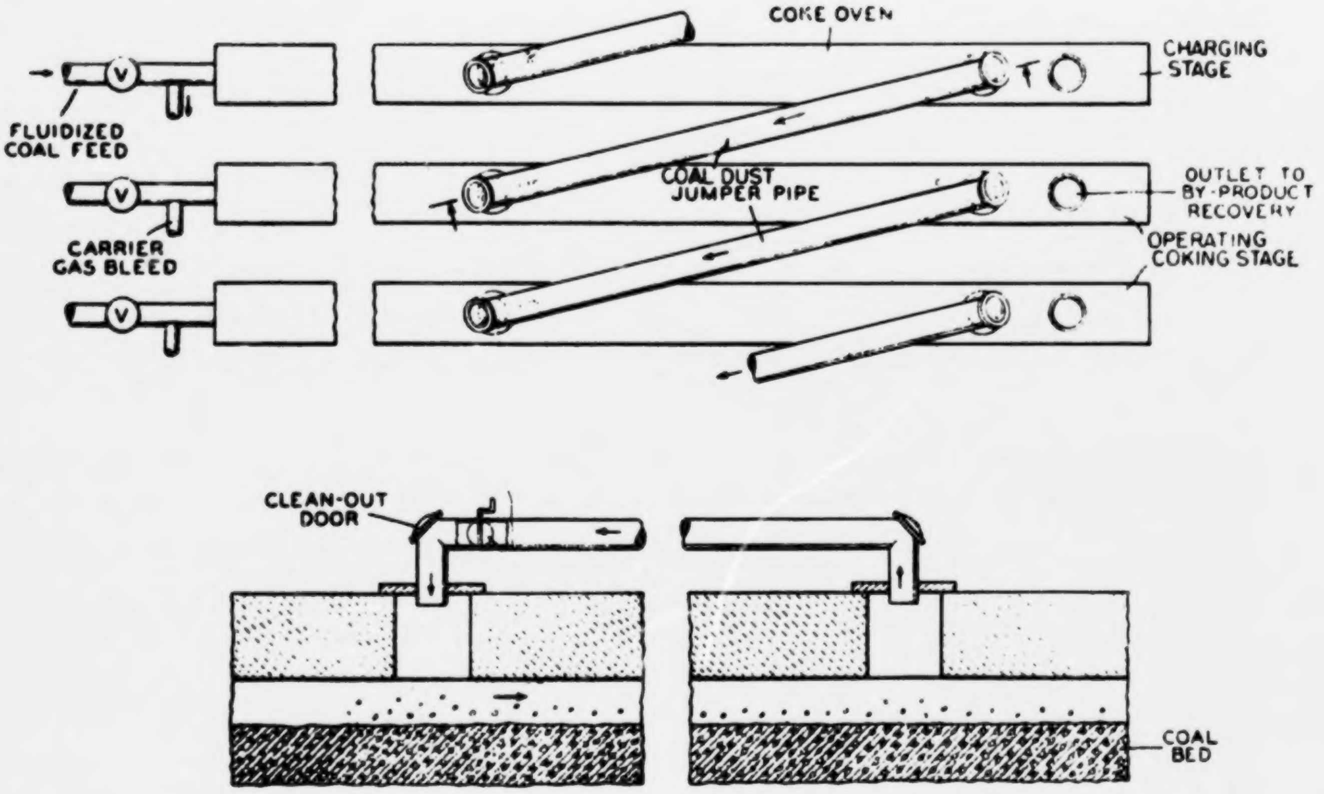

COKE OVEN
CHARGING STAGE
FLUIDIZED COAL FEED
V
CARRIER GAS BLEED
COAL DUST JUMPER PIPE
OUTLET TO BY-PRODUCT RECOVERY
OPERATING COKING STAGE
CLEAN-OUT DOOR
COAL BED

FIGURE III-18. VIEW AND SECTION OF PERMANENT JUMPER-PIPE SYSTEM FOR DISENTRAINMENT OF COAL DUST DURING PIPELINE CHARGING

Source: U. S. Patent No. 3,438,867

are ignited and burned with inspired air, then ducted to one or more scrubbing systems which collect the remaining dust and condensates. Finally, the cleaned gases are exhausted via stacks on top of the larry car. All equipment for direct collection and wet scrubbing of charging smoke is mounted on the larry car, or on a trailer to the larry car if the added weight must be distributed.

Some of the versions of the direct-collection approach are shown in Figure III-19. Even within a given make or type, there may be subtypes based upon differences in the scrubber(s), the manifolding, and the provisions for inspiring and carbureting the combustion air in controlled proportions. For the purposes of this report, presentation and comparison of details is limited to (1) the Koppers version with multiple scrubbers, and (2) the Hartung und Kuhn version of the Krupp design with ducting to a single scrubber.

Because direct collection and wet scrubbing systems must exhaust all gases and other material that the scrubber passes, the adequate removal of noxious materials depends upon efficient performance of three critical steps:

(1) Collection of the smoke

(2) Combusion of organic vapors and some dust

(3) Scrubbing of the products of combustion.

In turn, the ability of the equipment to perform the three critical steps well depends upon the following factors of design, operation, and maintenance:

(1) Provision of fresh water for the scrubbers, in sufficient amount to allow for delays in charging

(2) Design for adequate shrouding of the coal-charging ports, and sufficient draft to collect all the smoke

(3) Design for thorough air-gas mixing, appropriate control of inspired air, and assured complete ignition

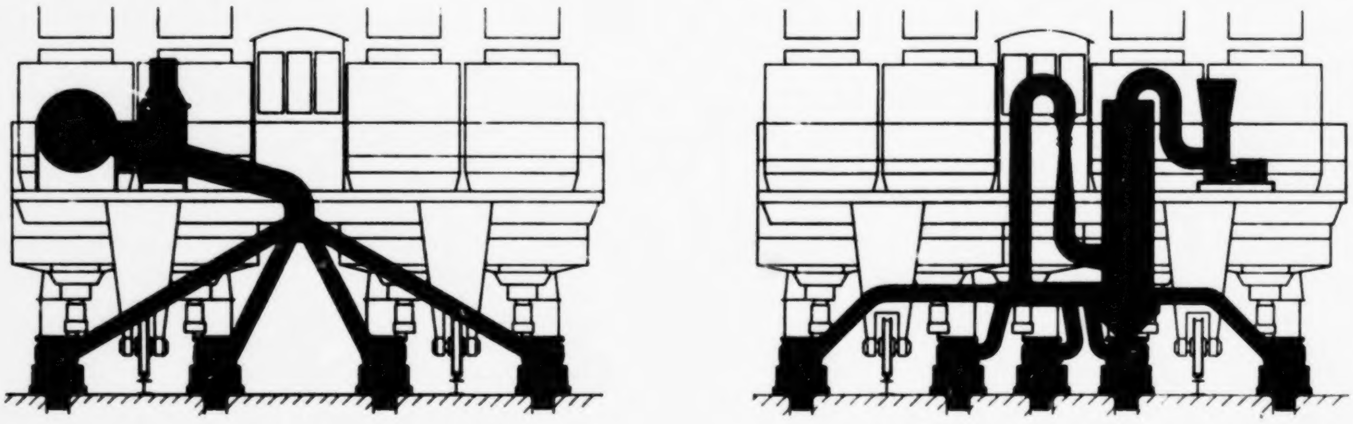
(4) Maintenance of clear ducts to facilitate draft and combustion, and to avoid buildup of combustible substances

(5) Maintenance of effective scrubbing and fan action, free from fouling and/or mechanical failure in continuous use

(6) Provision for discharge of fouled scrubber water into or through acceptable water-pollution controls.

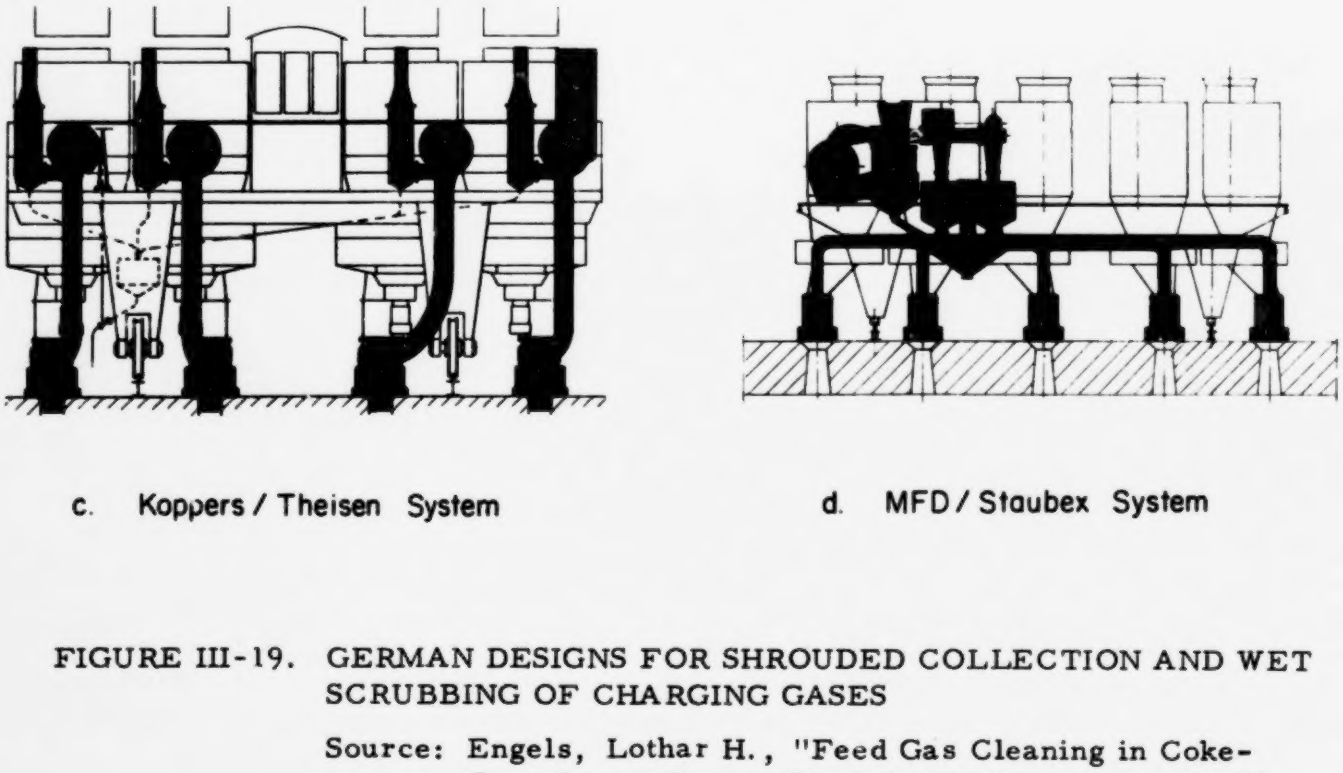
Although more than 60 (perhaps more than 80) larry cars have been and are being equipped for direct collection and wet scrubbing of charging smoke, most installations have had operating and maintenance problems. This system, though conceptually simpler than either pipeline charging or closed-port charging, has proved susceptible to defects in the details of design and maintenance. There is considerable competition and continuing development effort.

The Krupp scrubber device as built by Hartung und Kuhn is based upon manifolding all of the shrouds to a single Krupp flooded-disk wet scrubber. A line drawing of the overall system is shown in Figure III-20, and some details of the scrubber are shown in Figure III-21. This system was originally designed and installed for auto-ignition of



a. Krupp / Hartung und Kuhn System

b. Schalker Eisenhütte / CEAG System



c. Koppers / Theisen System

d. MFD / Staubex System

FIGURE III-19. GERMAN DESIGNS FOR SHROUDED COLLECTION AND WET SCRUBBING OF CHARGING GASES

Source: Engels, Lothar H., "Feed Gas Cleaning in Coke-Oven Larry Cars", Staub Reinhaltung der Luft, 26, 473-79 (1966)

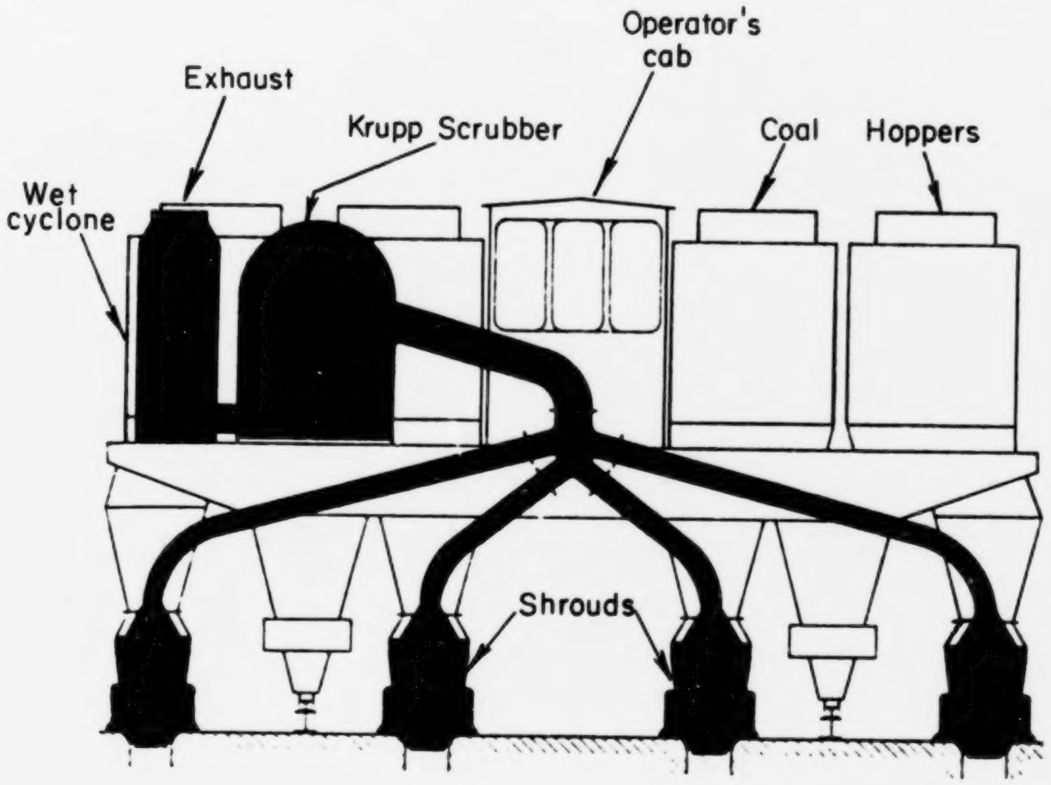

Operator's cab
Exhaust
Krupp Scrubber
Coal
Hoppers
Wet cyclone
Shrouds

FIGURE III-20. ELEVATION OF KRUPP/HARTUNG UND KUHN DIRECT SMOKE COLLECTION AND SCRUBBING SYSTEM

Source: Kutter, D. F., "Operating Trials of a Wet Scrubber for Cleaning Charging Gases", Glückauf, 100 (9), 516 (April, 1964)

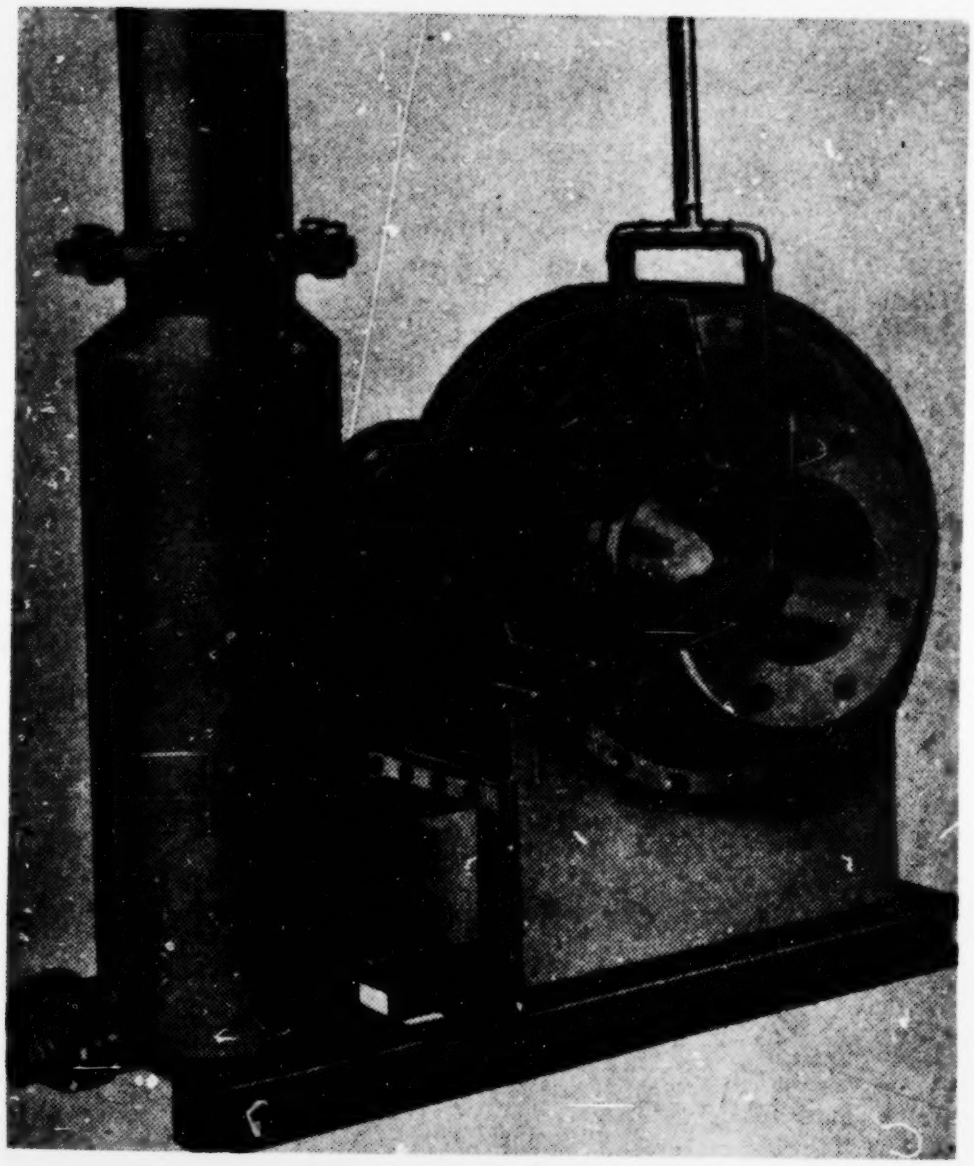


FIGURE III-21. CUTAWAY VIEW OF THE KRUPP SCRUBBER USED IN THE KRUPP/HARTUNG SMOKE-COLLECTING SYSTEM

Source: Kutter, D. F., "Operating Trials of a Wet Scrubber for Cleaning Charging Gases", Glückauf, 100, (9), 516 (April, 1964) the smoke in the shrouds, and auto-ignition is generally used with Hartung und Kuhn equipment in Germany. In Canada, Krupp/Hartung smoke systems were installed with electric glow-plug igniters, but the original igniters were not rugged enough or efficient enough in this service. Two Canadian installations and virtually all British and U. S. installations (of all makes) are being equipped for gas-fired ignition with propane or butane liquefied petroleum gas. At least in the United Kingdom, ignition with LP gas seems to be both effective and reliable. When ignition fails, organic materials are exhausted and also deposited in the ducting. Several kinds of system failure, including explosions, failure of draft, and scrubber malfunction have been traced to repeated failure to ignite.

German regulations require collection of 96 percent of particulate matter in charging smoke, and the systems offered for sale are tested to this standard. A British installer of the Krupp/Hartung system advised Battelle that its performance may be guaranteed if properly engineered by them for the conditions under which it is applied, but the guarantee did not include stipulation of any specific performance. In Canada, users noted some yellowish tinge to the scrubber exhaust even when ignition was provided, and they concluded that cleaning of the smoke was incomplete.

The Koppers variation of the direct-collection and scrubbing system is illustrated in Figure III-22. According to Koppers (both the German and the U. S. Koppers Companies supply this apparatus), the use of individual scrubbers is an advantageous innovation for several reasons:

(1) The draft may be adjusted to suit conditions at each port.

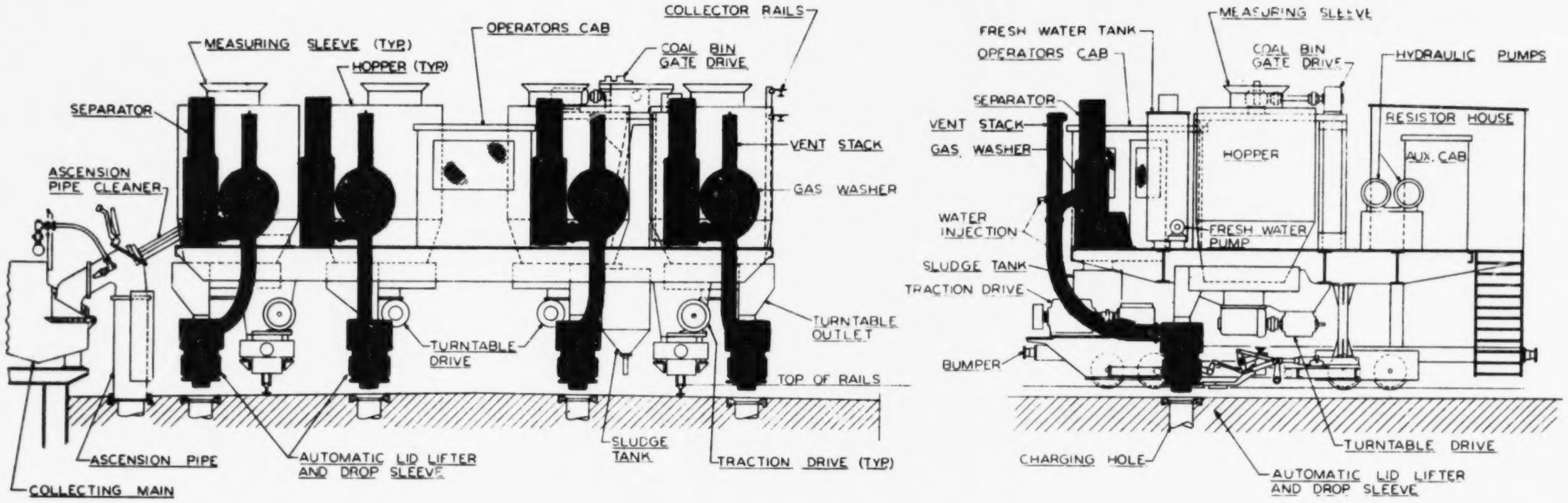
(2) The ductwork is simpler to demount for cleaning or replacement.

(3) More scrubbing is performed per unit of smoke collected.

Of these reasons, adjustable draft is probably the most important. At the port nearest the ascension pipe, and assuming that steam ejectors are used to draft the oven, scrubber draft may be most effective if fairly soft. Overdrafting at this point could put too much air into the air-smoke mixture, and could interfere with efficient combustion. At the other end of the larry car, the draft in the shroud should be stronger because draft from the ascension pipe has little effect. In addition, this far end is near an open chuck door for part of the charging cycle, and it is hoped that the escape of smoke from this opening may be retarded by a strong local draft. Koppers has contended that manifolding of ductwork as used in multiple-scrubber systems may permit accidental backdrafting down one or more of the ducts. Back drafts can cause explosions under some conditions.

Hartung und Kuhn is trying to eliminate moving parts from their design by replacing the centrifugal scrubber with a steam-powered venturi scrubber. (The Schalker-Eisenhütte system has a venturi scrubber too, but it is not steam powered.) Some experiments have shown that the steam venturi is both efficient and quiet, but generation of steam on the mobile larry car is a problem. Upon completion of some tests now in progress, Hartung und Kuhn plans to equip a larry car with a steam venturi drawing steam from an electric flash boiler. The tradeoff between no-moving-parts simplicity and portable-boiler complexity will have to be examined during these trials.

The present state of the art with regard to the latest systems installed in the United States is limited to direct collection and wet scrubbing of smoke. No other


MEASURING SLEEVE (TYP)
HOPPER (TYP)
OPERATORS CAB
COLLECTOR RAILS
COAL BIN GATE DRIVE
SEPARATOR
VENT STACK
GAS WASHER
ASCENSION PIPE CLEANER
TURNTABLE OUTLET
TURNTABLE DRIVE
TOP OF RAILS
SLUDGE TANK
TRACTION DRIVE (TYP)
AUTOMATIC LID LIFTER AND DROP SLEEVE
ASCENSION PIPE
COLLECTING MAIN
FRESH WATER TANK
OPERATORS CAB
MEASURING SLEEVE
COAL BIN GATE DRIVE
HYDRAULIC PUMPS
SEPARATOR
VENT STACK
GAS WASHER
HOPPER
RESISTOR HOUSE
AUX. CAB
WATER INJECTION
FRESH WATER PUMP
SLUDGE TANK
TRACTION DRIVE
BUMPER
CHARGING HOLE
TURNTABLE DRIVE
AUTOMATIC LID LIFTER AND DROP SLEEVE

COAL CHARGING CAR
FRONT VIEW

COAL CHARGING CAR
SIDE VIEW

FIGURE III-22. KOPPERS/THEISEN DIRECT COLLECTION AND WET SCRUBBING SYSTEM FOR CONTROL OF CHARGING SMOKE

Source: Koppers Company (U.S.A.)

high-efficiency approach (over and above various forms of charging on the main) has been installed in North America at this writing. The concept of direct collection and wet scrubbing has had a relatively long period of use to go through some of the inevitable evolution and modification of design. Practical problems, such as weight, water take-on and discharge, and ignition, now seem to have been largely solved. Nearly all large new coke plants in this country have been equipped with direct-collection devices, and several varieties will be operating at the time closed-port and pipeline charging make their respective debuts. Direct comparisons among these systems will involve problems of deciding where to collect samples of emissions. It follows that targets for control of charging smoke must be phrased in ways that may be interpreted for each of the systems.

Simon-Carves told Battelle that they are installing a larry car for preheated coal to be charged well below the temperature where flash ignition becomes a problem.* In this range of lower temperatures, about half the conserved energy is used for drying, and that portion of preheat which is converted to steam is largely recuperable. In air-pollution terms, predrying of coal at modest temperatures would tend to eliminate flash steaming during charging, and should make any smoke-control device function better. Simon-Carves plans to use a direct-collector device on their hot larry car, but will not ignite the smoke ahead of the wet scrubber.

Other Systems. Beyond consideration of the three systems involving pipeline charging, charging on the main with closed coal ports, and direct smoke collection, there is a large conceptual and practical gap. Systems that are fundamentally different from these do exist, but they have not been reduced to practice with risk capital. Accordingly, Battelle relegates them to a position of potential contenders.

One such system is a preheating and sealed-port charging system conceived by Didier-Werke, a German builder of coke ovens. In this concept, which has advanced to the status of a formal proposal, preheated coal is conveyed from a storage bunker across the top of the battery in a closed hot conveyor. Upon arrival at the oven, the hot coal is dropped through vertical chutes permanently fixed to the charging ports. Didier points out that this approach will require only one or two charging ports per oven because dry coal has a low angle of repose, and that it is fail-safe (as compared with closed-port charging) because all seals are permanent. Didier also expects this system to be less susceptible to carryover problems (as compared with both closed-port and pipeline charging) because no artificial drafts are used.

British Patent No. 932,886, issued in 1963 to an unnamed German firm, showed a double-pipe smoke-distribution system for permanent attachment along the row of ovens, at the side of the battery opposite the collector main. During charging, the suction side of this manifold system is opened only to the oven being charged, and the pressure side is vented to as many additional ovens as are required to dissipate the smoke. The British system is described in terms that would indicate that it has not been installed at full scale. A similar system has been tried in the Soviet Union. Nothing has been published about its performance.

---

*It is notable that in energy terms, heating a coal that originates at 8 percent moisture and 60 F to a final temperature of 300 F will require and conserve about 180 Btu per pound. Further heating to 500 F will require and conserve just under 70 additional Btu per pound of dry coal. This would indicate that the incremental increased difficulty, associated with higher temperatures where spontaneous ignition of the coal may occur, may not be offset by productivity gains.

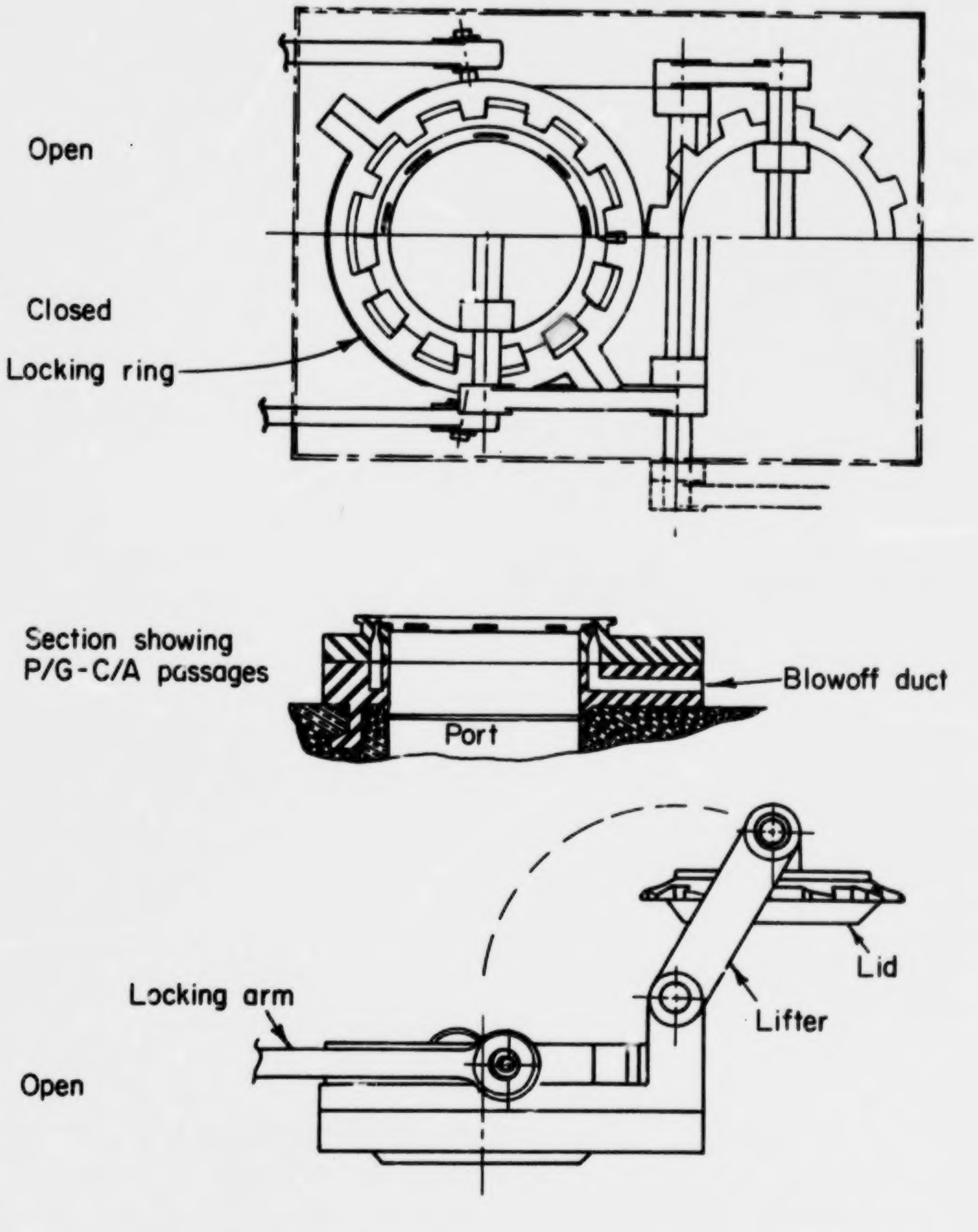

Open
Closed
Locking ring
Section showing
P/G-C/A passages
Blowoff duct
Port
Lid
Locking arm
Lifter
Open

FIGURE III-23. VIEWS OF TAILOR AND COMPANY DESIGN FOR A LOCKING, SELF-CLEARING CHARGING PORT

Source: Tailor and Company, Bettendorf, Iowa

Tailor and Company, of Bettendorf, Iowa, has proposed a system in the following terms:

> "The basic process outlined by us for preheating and injection is capable of being modified to meet special conditions. We prefer to discuss these optional methods at a later date.....
>
> "I would outline the options available as follows:
>
> 1. Preheating only and utilizing present larry cars for transport with ventilation provided at the charge point.
>
> 2. Preheating only with a pneumatic-gravity charge system.
>
> "Our method of preheating utilizes the Cross Flo technique which we are selling to the chemical, pharmaceutical, and food industries. A number of methods can be used for movement of materials from the preheater in the event the pneumatic system is not deemed feasible. It is our opinion that pneumatics offer the greatest potential utilizing our Zero Clearance Feeder."

Information submitted by Tailor was too limited for Battelle to determine and compare details. Also, the description indicated that the details are not firm. A drawing provided by Tailor and Company (Figure III-23) shows a charging port with locked closure, pneumatic cleaning, and integral unlocking/removal arms.

Finally, there are a few smoke-control systems which provide exhausting of smoke through a burner and chimney without scrubbing, as shown in Figure III-24. This is not considered to be a true air-pollution control, and was not studied.

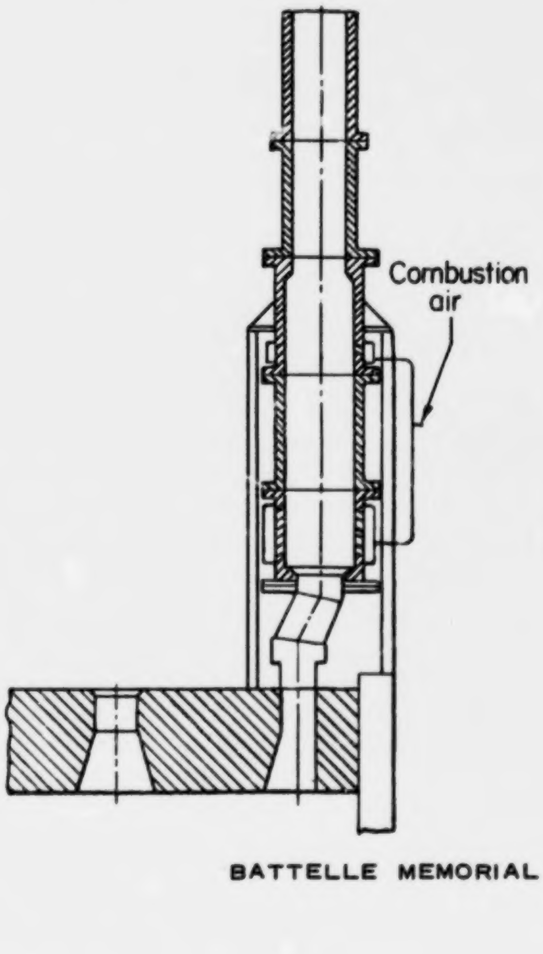


FIGURE III-24. COMBUSTION SMOKESTACK FOR CHARGING GASES

Source: "Coke Oven Technology", Coke & Gas, 23, 411 (1961)

Underfiring the Slot Ovens With Coke-Oven Gas

Coal newly charged to a slot coke oven is progressively heated from ambient temperature to a final temperature that is usually in the range 2150 to 2350 F. The coal closest to the hot sidewalls of the oven is heated fastest, and the coal along the central plane of the charge (midway between the sidewalls) reaches final temperature last. As its temperature is raised, coal goes through the complex series of physical, chemical, and morphological changes that convert it finally to coke. The means of supplying heat to a conventional coke oven is known as underfiring.

Apparatus and Operations

Underfiring derives its name from the physical arrangements for heating a coke oven. Fuel (normally gas) and air are mixed and burned at the base of long flues (vertical in modern ovens) that are provided in the interwalls between coking slots. One set of flues heats one wall of each of two ovens. The principal differences between designs of different builders lie in the arrangement of flues and other firing equipment. Most of the space below the ovens themselves is filled with chambers containing brick checkerwork for regenerative recovery of waste heat from spent combustion gases leaving the coke-oven flues. Two flue arrangements most commonly used in the U. S. are illustrated in Figure II-3. Figure III-25 shows a third design now being marketed for U. S. use, but which is not yet in use here.

The two gases most used for underfiring are blast-furnace gas (known also as lean gas) and coke-oven gas (known also as rich gas). Commonly, plants do not blend these two gases in various proportions. AISI statistics for 1968 show use of:

115.96 thousand million Btu of coke-oven gas
32.37 thousand million Btu from blast-furnace gas
15 to 17 thousand million Btu from natural gas and oil (estimated)

in the underfiring of coke ovens. Total underfiring energy per pound of coal on a dry basis is about 950 to 1,080 Btu - typically, 1,020 Btu per pound of coal.

When heating with rich gas, all of the regenerative checkerwork at the base of the oven is used for preheating combustion air. When heating with lean gas, both the gas and the air normally are preheated. Many coke ovens are equipped (as in Figure III-25) to use either gas. Regenerative cycling of flues and checker chambers is automatically reversed, typically on a 20-minute cycle. All arrangements are carefully controlled to give the most uniform wall temperatures possible from end to end of the oven. Some operators seek to keep the top of the oven walls just a little cooler than the average wall temperature in order to minimize the deposition of carbon on the oven roof. A battery of 80 conventional ovens has a heated wall area of two acres or more; provisions for combustion control and heat distribution are necessarily elaborate.

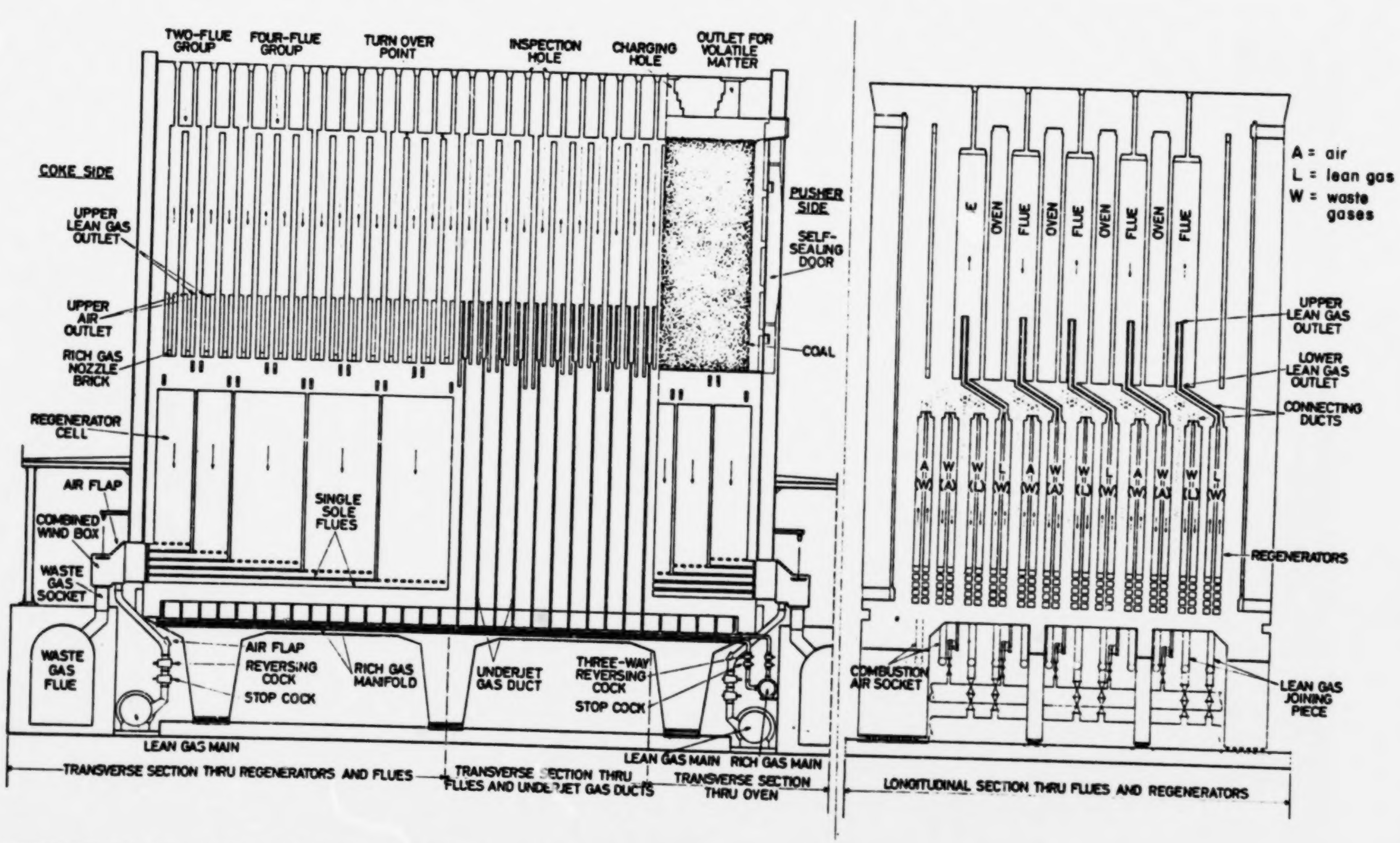

TWO-FLUE GROUP
FOUR-FLUE GROUP
TURN OVER POINT
INSPECTION HOLE
CHARGING HOLE
OUTLET FOR VOLATILE MATTER
COKE SIDE
UPPER LEAN GAS OUTLET
UPPER AIR OUTLET
RICH GAS NOZZLE BRICK
REGENERATOR CELL
AIR FLAP
COMBINED WIND BOX
WASTE GAS SOCKET
WASTE GAS FLUE
SINGLE SOLE FLUES
PUSHER SIDE
SELF-SEALING DOOR
COAL
AIR FLAP
REVERSING COCK
STOP COCK
RICH GAS MANIFOLD
UNDERJET GAS DUCT
THREE-WAY REVERSING COCK
STOP COCK
LEAN GAS MAIN
LEAN GAS MAIN
RICH GAS MAIN
TRANSVERSE SECTION THRU REGENERATORS AND FLUES
TRANSVERSE SECTION THRU FLUES AND UNDERJET GAS DUCTS
TRANSVERSE SECTION THRU OVEN
E
OVEN
FLUE
OVEN
FLUE
OVEN
FLUE
OVEN
FLUE
A = air
L = lean gas
W = waste gases
UPPER LEAN GAS OUTLET
LOWER LEAN GAS OUTLET
CONNECTING DUCTS
A (W)
W (A)
W (L)
L (W)
A (W)
W (A)
W (L)
L (W)
A (W)
W (A)
W (L)
L (W)
REGENERATORS
COMBUSTION AIR SOCKET
LEAN GAS JOINING PIECE
LONGITUDINAL SECTION THRU FLUES AND REGENERATORS

FIGURE III-25. SECTIONS THROUGH A BATTERY OF "DIDIER FLOW-CONTROLLED COKE OVENS" OF UNDERJET, COMPOUND TYPE WITH HEATING-FLUE GROUPS

The shown charging of the regenerator chambers and of the remaining heating system represents a reversing semicycle when heating with lean gas. The charging of the regenerator chambers for the next reversing semicycle is in parentheses.

Source: Didier-Werke AG., Industrieanlagenbau Essen

Emissions

The system for underfiring a coke oven is probably more sophisticated than in most boiler plants. It burns an ash-free fuel, and operates at modest flame temperatures such that noxious gases form only in small amounts. The underfiring system of a coke plant, taken as an operating unit, contributes little to air pollution, except to the extent that the fuel contains sulfur.

The burning of coke-oven gas for underfiring is a source of sulfur emissions. If there is no blast-furnace plant near the coke plant, or if cheap blast-furnace gas is committed to the firing of soaking pits and boilers, coke-oven gas is the prime source of underfiring energy. Even among the steelmakers, most of whose plants have both gases on-site, coke-oven gas provides 70 percent of total underfiring energy. Among merchant coke plants, coke-oven gas is used almost exclusively. According to AISI statistics for 1968, the underfiring of coke ovens consumed roughly 35 percent of the total coke-oven gas produced in any one plant, and accounted for 26.3 percent of total steel-industry consumption of coke-oven gas.

The origin of sulfur in coke-oven gas is primarily from the reaction

$$H_2 + FeS_2 \rightarrow H_2S + FeS \quad ,$$

which proceeds freely within the coke ovens. Some German work in the late 1950's indicated that injection of hydrogen into a coke oven could lead to almost complete removal of the pyritic sulfur, leaving ferrous sulfide under most conditions. Virtually all of the sulfur in coke-oven gas is present as hydrogen sulfide. The normal range is from 3.5 (rare) to 4.5 grains of hydrogen sulfide per standard cubic foot of coke-oven gas (as distributed from the booster station). The typical hydrogen sulfide content is 4.2 grains, which corresponds to 3.95 grains of sulfur per standard cubic foot of coke-oven gas.

How serious an emission is the sulfur dioxide formed from burning coke-oven gas? There are three ways of looking at it:

(1) On an energy basis, the sulfur in a 550 Btu/cu ft gas at 4.2 grains H_2S is equivalent to 1.44 percent sulfur in a 14,000 Btu/lb bituminous coal.

(2) The coke-oven gas used for underfiring coke ovens by the steel industry in 1968 accounted for up to 119 million pounds of sulfur emissions. The total coke-oven gas used by steelmakers contained up to 450 million pounds of sulfur.

(3) Coke-oven gas, unless processed to remove hydrogen sulfide, is a significant source of sulfur dioxide, but must be ranked far below coal itself as a problem. Unlike coal, coke-oven gas can be stripped of sulfur with existing technology.

Some steelmakers strip the hydrogen sulfide from their coke-oven gas, but this practice is far from universal. It is not generally considered to be a worthwhile practice, except in large coke plants or where the gas is used in operations metallurgically sensitive to sulfur. There are some plants which convert stripped hydrogen sulfide to sulfuric acid for use in by-product operations and/or pickling, but some of the plants which strip hydrogen sulfide merely vent it, so that there is not any lowering of air pollution. Cost data obtained during the earlier study of the steel industry (see Section II) indicated that stripping of hydrogen sulfide could easily cost more than the coke-oven gas is worth as a fuel.

Alleviation

The alleviation of pollution of the air by sulfur dioxide from underfiring with coke-oven gas is not discussed in detail in this report. One clear method is to use blast-furnace gas or natural gas for underfiring. This is only partly useful in the practical sense, and contributes nothing overall because coke-oven gas must be used, flared, or vented somewhere.

Older processes for stripping gas are based upon absorption of the hydrogen sulfide in soda-ash solution (the Seaboard process and analogues). This method is only 70 to 80 percent efficient. If additional stripping of H_2S is required, the coke-oven gas is passed through boxes containing iron powder. Both the Seaboard process and the iron-powder operation are quite expensive, and the hydrogen sulfide is not collected in marketable forms. The soda-ash solution used in the Seaboard process is regenerated by heating to drive off dissolved H_2S.

Newer processes for gas stripping are based upon caustic solution or ammoniacal liquor. To preserve solution efficiency, they may include a preliminary stage for removal of trace hydrogen cyanide too. The products of stripping (99 percent pure sulfur in the case of the caustic Stretford process) are more usable or salable, and the costs are somewhat lower. An operating cost of $0.02 per million Btu has been claimed (after sulfur credits) for the Stretford process applied at 24 million cubic feet of gas processed per day, in the United Kingdom. Addition of corporate costs, U. S. differentials, and marketing costs could make the total cost double or triple the operating cost, but Stretford processing would still be relatively attractive in comparison with older methods.

Sealing of Slot Ovens During Early Stages of Coking

As coal is heated, it goes through the following principal changes within the slot oven (temperatures are approximate):

(1) Drying (200 to 400 F)

(2) Transformation to plastic state; release of light aromatic vapors plus some hydrogen and methane (500 to 900 F)

(3) Breakdown of most organic compounds; vaporization of the intermediate fractions and breakdown products (tarry compounds from benzene to anthracene); agglomeration of residues in a spongy semisolid mass (1000 to 1500 F)

(4) Final breakdown of the most stable organic materials; some release of additional hydrogen; formation of final coke structure as a cellular graphitic solid (1600 to 2500 F).

To the extent that the above reactions develop internal gas pressures that cannot be fully accommodated by the by-product collection system, and to the extent that the ovens have leaks of various kinds, some of the vapors and gases forced out of the coal may become emissions.

Apparatus and Operations

The primary sealing fixtures of a conventional coke oven are the end doors and the charging ports. The end door at the pusher side of the oven has an additional outlet, known as the chuck door, through which the leveler bar operates. Leakage of tarry smoke can occur at any or all of these sites.

The sealing of the charging ports is based upon the dead weight of the charging-port lids, which seat against steel sealing rings embedded in the brickwork. Because the normal weight of a lid is considerably greater than the forces developed inside an oven, leakage occurs only if the sealing surfaces meet imperfectly. There are two ways this can occur: by intrusion of tarry deposits or particles of fresh coal on the mating surfaces, and by warpage or damage to the mating pieces.

The sealing of the doors is much more elaborate than the sealing of the lids. Older ovens still use "luted" doors, which are sealed with fresh clay applied as a gasket material. By far the majority of coke-oven doors, however, are sealed by narrow steel strips forced in T-configuration against flat iron or steel jamb castings. The sealing strips are mounted so that they may be adjusted to fit worn or warped jambs, or in one design so that they may be forcibly conformed to the jamb by spring action. Some designs for the mounting of seal strips are illustrated in Figure III-26. Locking action for coke-oven end doors has taken many forms, including screws, cams, gravity acting on levers, pneumatic cylinders, and springs. Because simple locking is preferred for actuation by semiautomatic door-removal machines, screw and cam locks have predominated in the United States.

So-called self-sealing doors (those having steel strips) seal by the deposition of small amounts of tar at the sealing edge. This leads to buildups of hard tar which must be scraped away. All coke-oven builders recommend thorough cleaning of the seal areas of doors and jambs before every coking cycle. Equipment for mechanized cleaning of seals and jambs has been built for years. One of the better versions (made available to Battelle as drawings) is shown in Figures III-27 and III-28. However, most users regard all mechanical cleaning as incomplete and unreliable. At the very least, hand touch-up or elaborate and continued adjustment of the cleaning machines is required.

The sealing of doors on new taller ovens is much more difficult than on conventional ovens up to 4.5 meters (14 feet) high. According to the mechanical principle that a beam of given section will deflect in accord with the cube of its length, it is difficult to design a tall-oven door that is both light enough to handle and stiff enough to seal well. It is also much more difficult to clean a tall door, either mechanically or by hand.

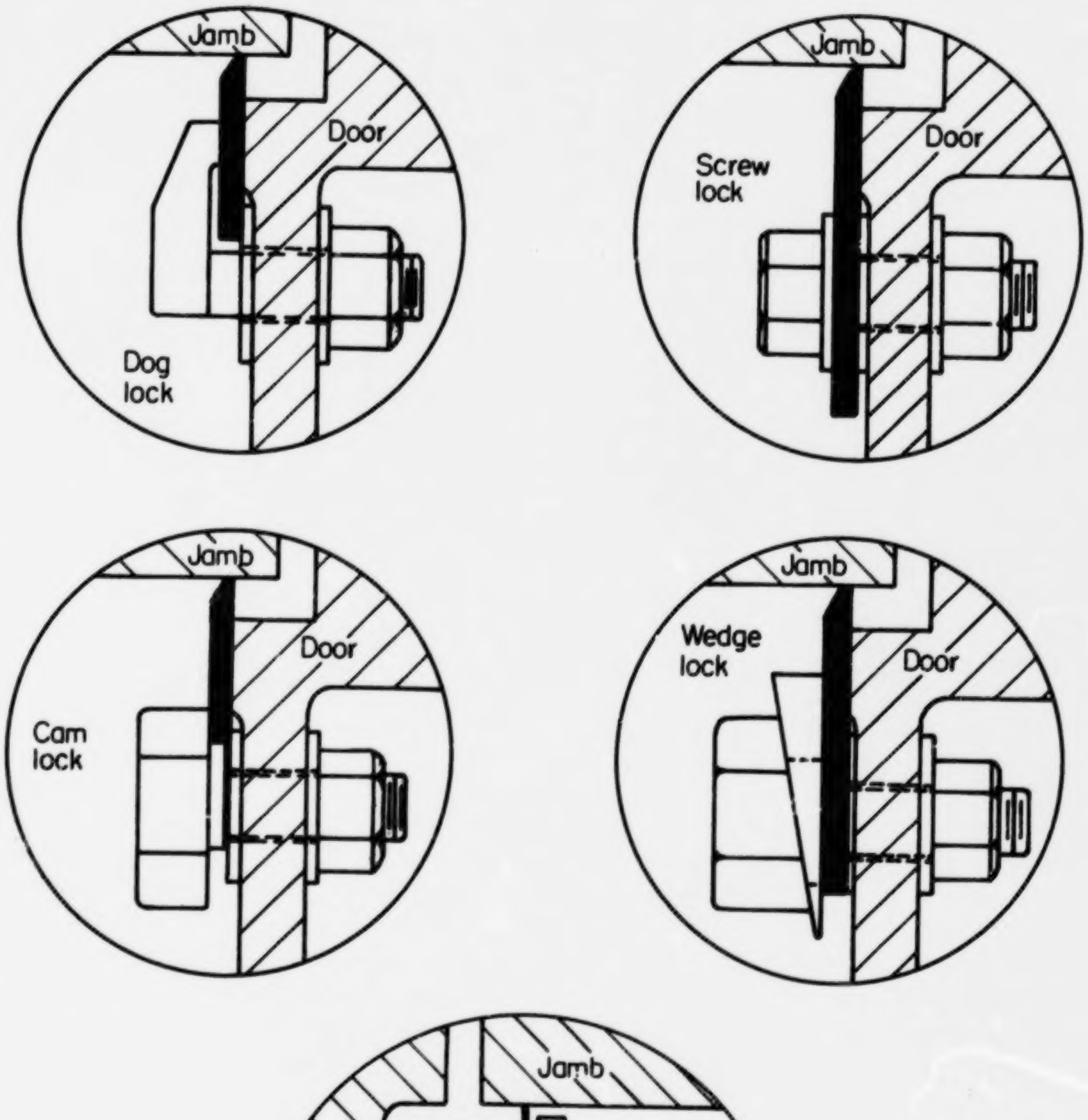

Jamb
Door
Dog lock
Jamb
Door
Screw lock
Jamb
Door
Cam lock
Jamb
Wedge lock
Door
Jamb
Door
S-bend seal with spring loading

FIGURE III-26. SECTIONAL VIEWS OF ARRANGEMENTS FOR ADJUSTING AND HOLDING COKE-OVEN DOOR SEALS

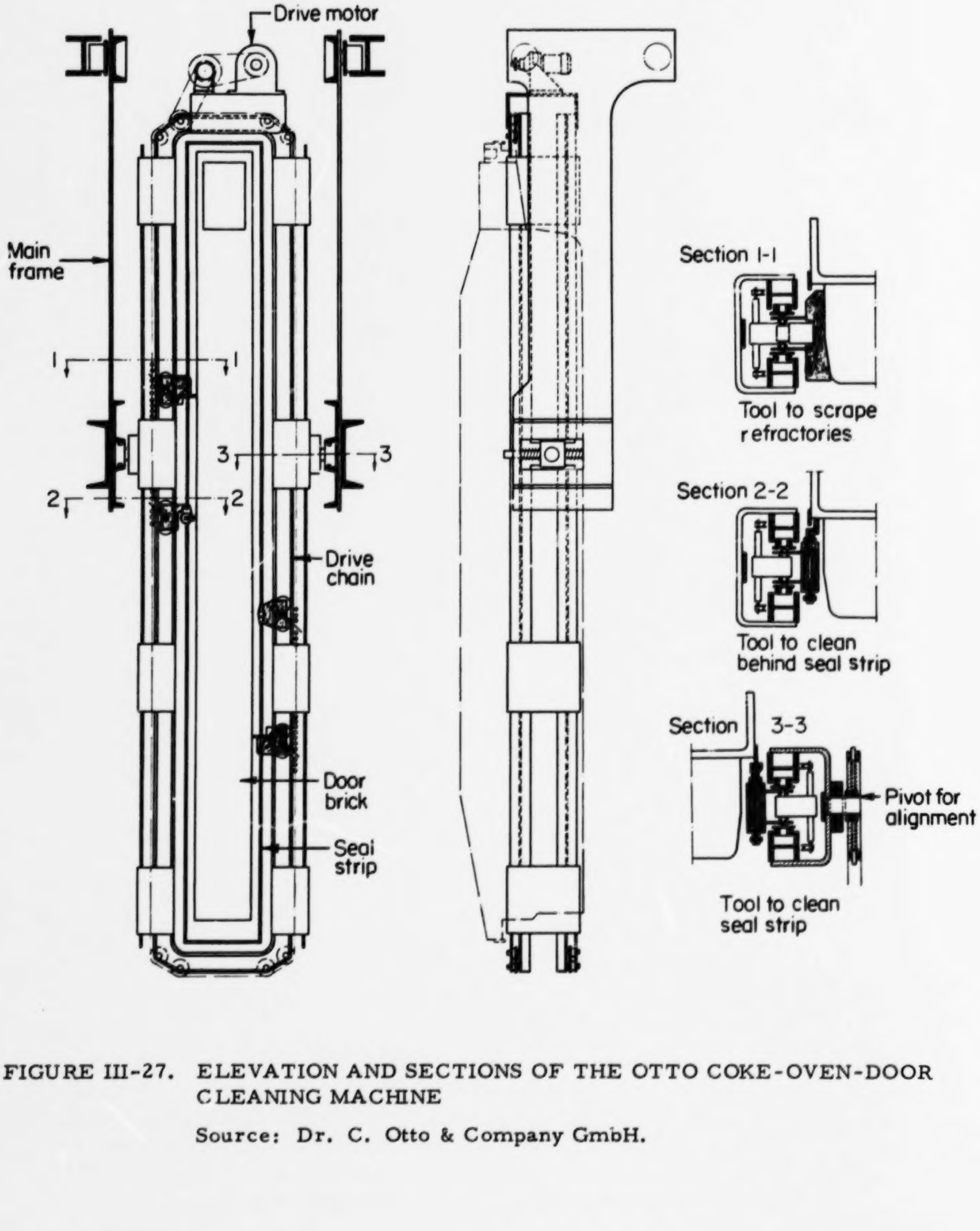

Drive motor
Main frame
1
1
3
3
2
2
Drive chain
Door brick
Seal strip
Section 1-1
Tool to scrape refractories
Section 2-2
Tool to clean behind seal strip
Section 3-3
Pivot for alignment
Tool to clean seal strip

FIGURE III-27. ELEVATION AND SECTIONS OF THE OTTO COKE-OVEN-DOOR CLEANING MACHINE

Source: Dr. C. Otto & Company GmbH.

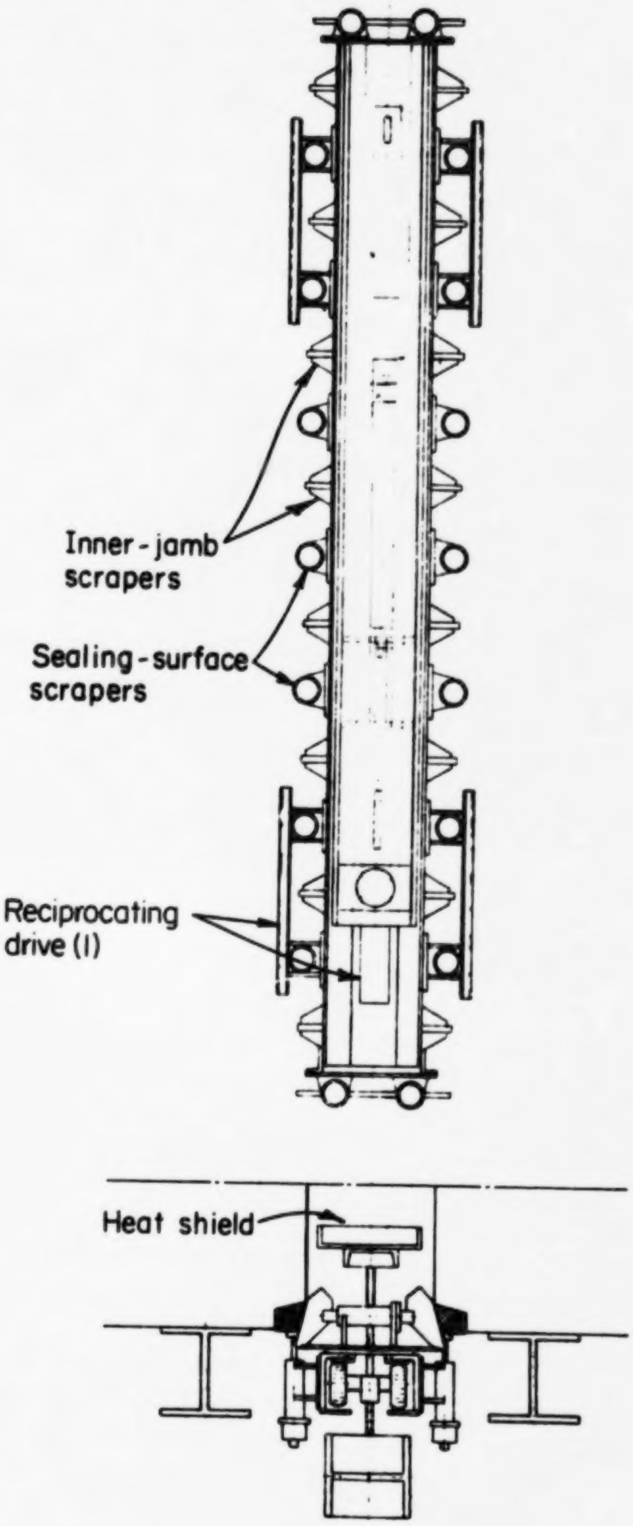

Inner-jamb scrapers
Sealing-surface scrapers
Reciprocating drive (1)
Heat shield

FIGURE III-28. ELEVATION AND SECTION OF THE OTTO JAMB-CLEANING MACHINE

Source: Dr. C. Otto & Company GmbH.

Emissions

If coal dust is left on a charging-port seat, or if coal is swept into the small opening around the lid outside the seal zone, this coal will smoke as the lid gets hot. The displacement of the lid from sealed position will allow oven gases to leak out in modest amounts. The pressure differential between the free space in the oven and the outside air is relatively small, however, and a well-seated lid should not release smoke at any time.

In actual practice there are two kinds of leaks from self-sealing or luted doors:

(1) Leakage that occurs because doors are not properly cleaned and adjusted, or because seal strips or jambs are warped beyond hope of meeting one another. This leakage is a heavy brown smoke during the first stages of coking (while steam is still being evolved from wet coal) and continues with yellowish smoke and exuding tar throughout most of the coking cycle.

(2) Leakage that occurs because well-maintained doors and jambs still cannot form a perfect seal until they have accumulated some tar deposits. This leakage is a light brown or yellow smoke during the first hour of coking, after which it stops. Really good doors may leak for only 10 minutes.

Most coke plants experience leaks somewhere between these two extremes. The extent of emissions at any given plant depends greatly on the amount of attention paid to the leakage problem by the operating personnel.

Alleviation

As shown by the Russian example in Figure III-29, charging-port lids can be designed for easy cleaning, positive seating, and good concentration of sealing forces. The practice of sweeping spillage into and onto the lids has virtually disappeared in the U. S., and this has certainly helped. New lid-handling machinery being offered is capable of rotating the lids rapidly as they are reseated, and this rubbing action should help form good seals if wear is not excessive.

Door sealing is becoming a bigger problem with the taller ovens, and at this time no maker of door-cleaning equipment has come up with a completely adequate design. Work on this problem is in progress, in hopes that the seals themselves need not be changed. Without choosing among the various designs illustrated in Figure III-26, it is clear that (1) all seals operate on the same T-joint principle and (2) all depend upon good maintenance. Seals based upon elastic materials or asbestos have been tried from time to time, but none has succeeded because these materials are all subject to damage from wear, tar, and/or cleaning operations.

At the Zollverein Works of the Rhein-Elbe Coal Company, Battelle's investigators were shown a system for the injection of coke-oven gas through the doors and thence into the open area around the door seals. The procedure is covered by German Patent No. 1,149,330. The principle is that the injected gas pressurizes the seal area and prevents migration of tarry smoke and vapors toward the jambs and seals. (At the bottom of the oven, the jambs and seals are wetted by flowing liquid tar, and back-pressurization with gas is ineffective for the lowest foot or so.) Most of the back-injected gas is merely recycled into the by-product system, but a small fraction of it (some of the methane) breaks down upon reexposure to high temperatures, and fluffy carbon powder is deposited to close the seals early in the cycle.

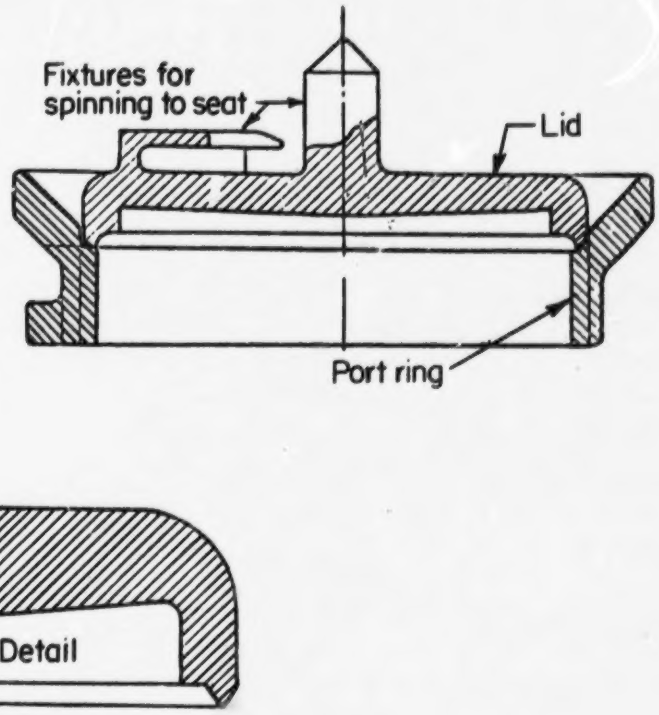


FIGURE III-29. RUSSIAN DESIGN FOR A POSITIVE-SEATING, ROTATABLE CHARGING-PORT LID

Source: Stanovskii Coke Works, as illustrated in Koks e Chimia (1963)

This system as installed at Zollverein has been abandoned there because it requires connection and disconnection of hoses on the doors at each cycle, and the extra effort was repudiated after 6 years of good performance. Zollverein's doors are now in poor condition and smoke incessantly, but both Zollverein and independent observers say the system worked well when in use. Simon-Carves, in England, has adapted the principle and is using it on new British coke ovens, with two improvements:

(1) Self-actuating check valves are provided to stop gas flow when the doors are removed

(2) Gas is ducted into the seal area through the door frames instead of the doors themselves.

These innovations will probably eliminate most of the nuisance and hazard objections that have been raised against the Zollverein installation.

The point of back-injection of gas is not that it keeps the doors and jambs entirely clean -- it doesn't. What it does do is make the seals easy to clean. The fluff carbon breaks up easily with normal mechanical cleaning, and any stray tar is deposited on a barrier layer of fluff carbon that provides an easily sheared base. As a result, the maintenance of doors (and especially of tall doors) is greatly eased and much improved. At the same time, the risk of losing considerable gas through badly fitted seals tends to increase interest in maintenance of mechanical fit. As designed by Simon-Carves, the back-pressurizing system uses about 5 percent of the total gas make, and returns at least two-thirds of that to the system. A small blower compresser is used to raise the gas pressure to 20 inches water column, and the gas is delivered through the door frames at (typically) 14 inches WC pressure. No extra operating steps are required.

Discharging of Newly Produced Coke

At the end of the coking cycle, after from 15 to 40 hours in the oven (typically 14 to 18 hours for blast-furnace coke), the finished coke is pushed out of the slot. This operation begins with removal of both end doors and positioning of a coke guide as is illustrated in Figure II-4. When the hot-coke car is in position (with one end of the car under the end of the coke guide), a signal is given and the large pusher ram is pressed against the opposite end of the coke. The ram behaves as a huge piston to force the mass of coke out of the oven, through the guide, and into the car.

Apparatus and Operations

Hot-coke cars (or quench cars, as they are also known) are designed as a sloped-bottom hopper about 60 feet long. This shape is intended to spread out the hot coke as it falls from the guide, so that in later steps it is easy to quench uniformly and discharge evenly from the car to the wharf. This spreading effect, and the moving of the car required to accomplish it during pushing, interferes with consideration of the push as a static operation amenable to close hooding or shrouding.

Similarly, the present usual design of door equipment requires a move along the battery benches. A first tool reaches for the door, releases it, and picks it up for removal. This apparatus must then be backed out of the way – on the pusher side for insertion of the ram head, and on the coke side for positioning of the guide. As in the case of the design of the hot-coke car, these usual design factors interfere with effective hooding or shrouding. It follows that any truly controlled system must include a total redesign of door machines, guides, rams, and hot-coke car.

The guide itself is conventionally made of steel straps arranged horizontally, with stringers of channel or angle on the exterior to keep the straps separated by an inch or two. The relief provided by the spaces between the straps is considered vital to the mechanics of pushing. If a solid-wall guide were built, coke could be expected to jam within it, and there would be risk of bent framing or even of pushing the whole guide off the bench with the coke. Again, the usual design is unfavorable to emissions control.

Emissions

The emissions during pushing are of two types and from three sources:

(1) Smoke from incompletely coked coals
   (a) From within the door-seal areas and adjacent to the door refractories, which are unheated
   (b) As a result of defective heating or inadequate coking time within the interior of the charge.

(2) Dust from thermal drafting of particles of abraded coke.

The smoke, when and as it is released, does not differ significantly from the charging smoke except that most pushing smoke is ignited. The amount of smoke is directly related to the amount of charged coal that has been insufficiently heated. The amount of coke dust depends upon the strength of the coke, the distance of free fall into the hot-coke car, and the physical design of the entire coke-side apparatus. Dust release also depends on wind direction and force, and on the amount of accumulated coal dust and coke dust on the bench, steelwork, and ground.

Alleviation

The most important factor in alleviating pushing emissions is the prevention of inadequate or inaccurate operations giving rise to "green" (smoky) coke. Green coke performs poorly in the blast furnace, thus it is rarely made deliberately. However, pressures for more hot metal, lost time in coking operations, or repairs to part of a coking plant can all lead to a decision to push a little ahead of normal schedules. In some older, partly deteriorating plants, it is possible to be surprised with a green push arising from a defect in the heating burners, flues, or checkerwork. In plants where basic conditions are good, a green push is most generally by operating error or by choice to gain production.

It is believed that for a given oven design and a given blend of coals, there is probably an optimal coal charge that will be fully coked on top without allowing free-space temperatures to rise too high. Unfortunately, some operators fill their ovens more fully than is appropriate in hopes of making a little more coke and holding roof temperatures (and accompanying carbon deposition) down. This practice is a prime source of green coke. Oven builders consider this source unnecessary if heating rates are appropriate to the flue design.

Figure III-30 illustrates, for the end of a coking cycle, the decline in expected rate of evolution of gas and vapor within the oven. If the oven is pushed at Time A indicated on the figure, the potential for smoke formation will be very high and the push very green, even though much of the charge may be fully coked. If the oven is pushed at Time C, the potential for smoke formation will be low. The indication of a 2-hour span during which smoke potential drops off sharply is approximate, but most ovens pushed 2 hours early will emit enough smoke and flame to be seen several miles away. The point is that a small cut in cycle time, as from the proper Time C back 3/4 hour to Time B, will produce a large increase in smoke, perhaps fivefold, for a minor

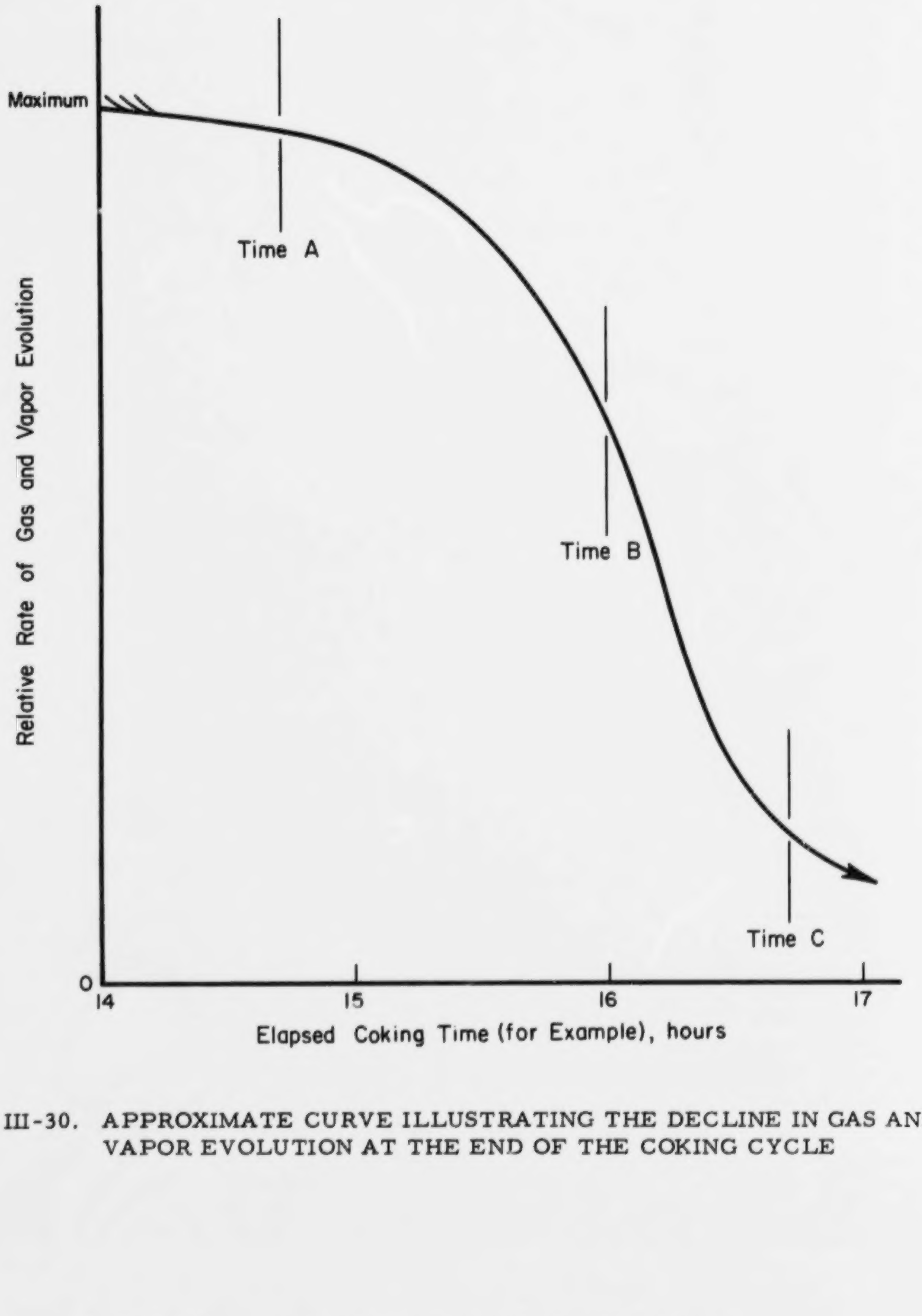


FIGURE III-30. APPROXIMATE CURVE ILLUSTRATING THE DECLINE IN GAS AND VAPOR EVOLUTION AT THE END OF THE COKING CYCLE

productivity gain of perhaps 5 percent. Given freedom to choose, a coke-plant operator will push at Time C to get better coke, safer operation, longer oven life, and a cleaner plant. Pushing ahead is known to be a calculated risk irrespective of its emissions effects.

From the standpoint of control of air pollution, the major problem is to capture the high volume of smoke that is released rapidly when green coke is pushed. A green push will not only flood a control device with gas and smoke, it is entirely likely to burn or distort at least part of the collection device, or cause other substantial damage to equipment. Accordingly, all of the hardware proposals studied by Battelle were based upon the premise that green pushes could be eliminated.

The only installed pushing-emissions controls at this time are hoods shaped like half-pyramids and cantilevered out over the hot-coke car trackage. One such hood is in Japan; the one seen by Battelle investigators was at Zollverein Plant in Essen, Germany. It was built by Hartung und Kuhn, and is equipped with twin exhausts leading down from the top into wet scrubbers mounted to either side of the guide dolly, over the coke-side bench. Drawings of this apparatus were promised but not provided, so Figure III-31 is a sketch from memory. The limits of cantilevering and total load on the bench precluded use of a hood big enough to cover the entire quench car. On normal pushing, as indicated in some movies, the hood did a fair, but incomplete, job of catching the smoke. On a green push, the hood was nearly burned down and had little effect on emissions. This approach suffered from very definite limitations imposed by the arrangement of the plant and the bearing capacity of the bench.

An important proposed pushing/quenching system is depicted in Figure III-32. This design, adapted by Heinrich Koppers from their method of quenching calcined petroleum coke, has been proposed for trial at the Cornigliano (Genoa) Works of Italsider, with sponsorship from the High Authority of the European Coal and Steel Community. The special machine, which is to be completely enclosed, will receive the coke into a large refractory-lined skip, which will then be discharged slowly into the quenching drum between pushes. Cooling and quenching sprays are provided at both ends of the drum which will fill with steam to prevent excessive oxidation loss. Steam and pushing gases will be exhausted through an emission-control device. It is expected by Koppers that any extra abrasion loss from the drum's rotation will be fully offset by the avoidance of quenching fractures usually associated with deluge quenching in a tower. At the cool end of the drum, the coke will be fed to a continuous conveyor running along the track.

A recent change, not shown in Figure III-32, is of major importance in the design of any emission control for pushing of coke ovens. As illustrated in Figure III-33, Heinrich Koppers has designed a "one-spot" door machine that indexes about a vertical axis to perform the operations of door removal, coke guiding, and door and jamb cleaning. Because this apparatus may be held in one spot from door-off to door-on, it can be effectively shrouded against the escape of most emissions except those accompanying the opening of the door, and even these can be partly hooded. Koppers will incorporate the one-spot door machine in the Cornigliano quencher, and Koppers of Pittsburgh is installing a similar apparatus for trial and demonstration at their plant in Kearny, New Jersey.

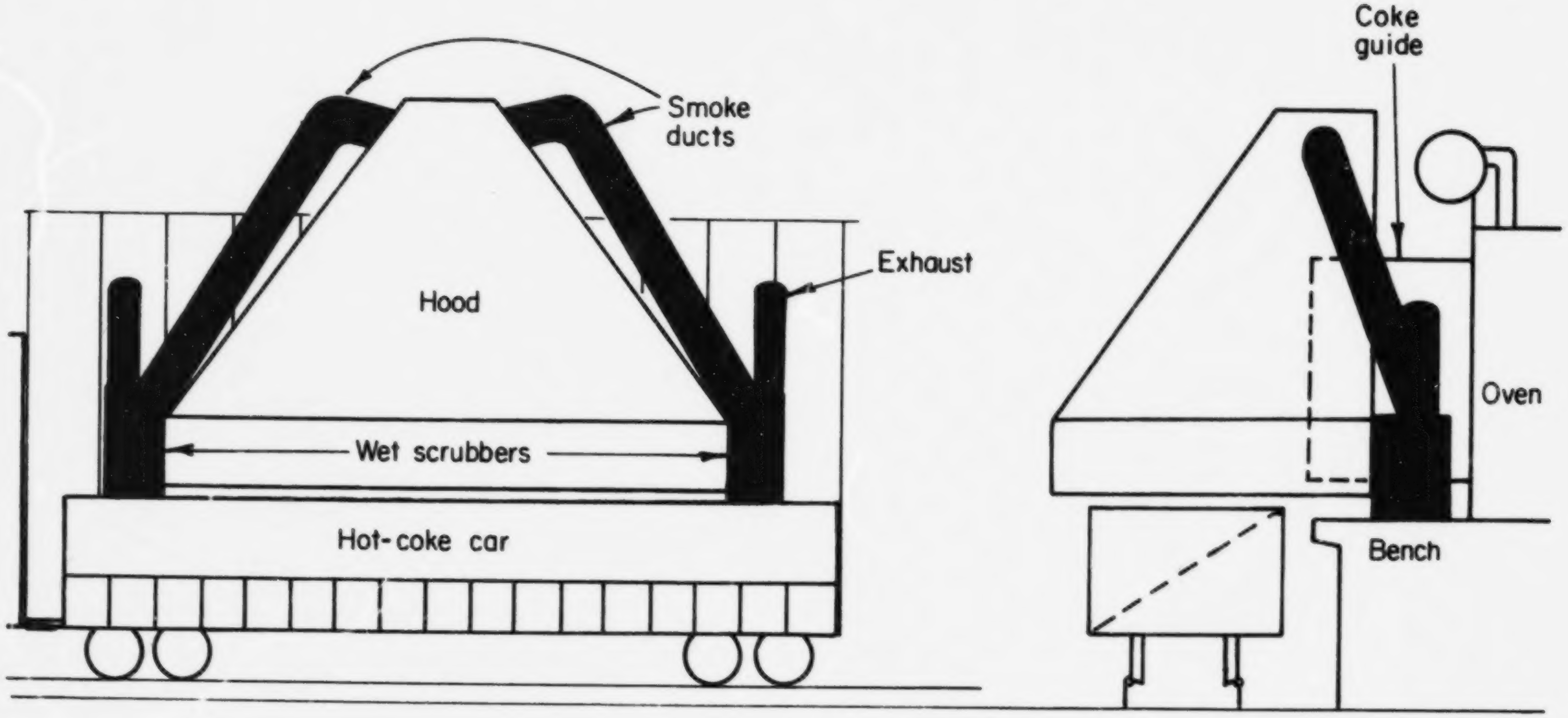

Smoke
ducts
Exhaust
Hood
Wet scrubbers
Hot-coke car
Coke
guide
Oven
Bench

FIGURE 31. SKETCH OF PUSHING HOOD INSTALLED BY HARTUNG UND KUHN AT ZOLLVEREIN WORKS OF RHEIN-ELBE COAL COMPANY

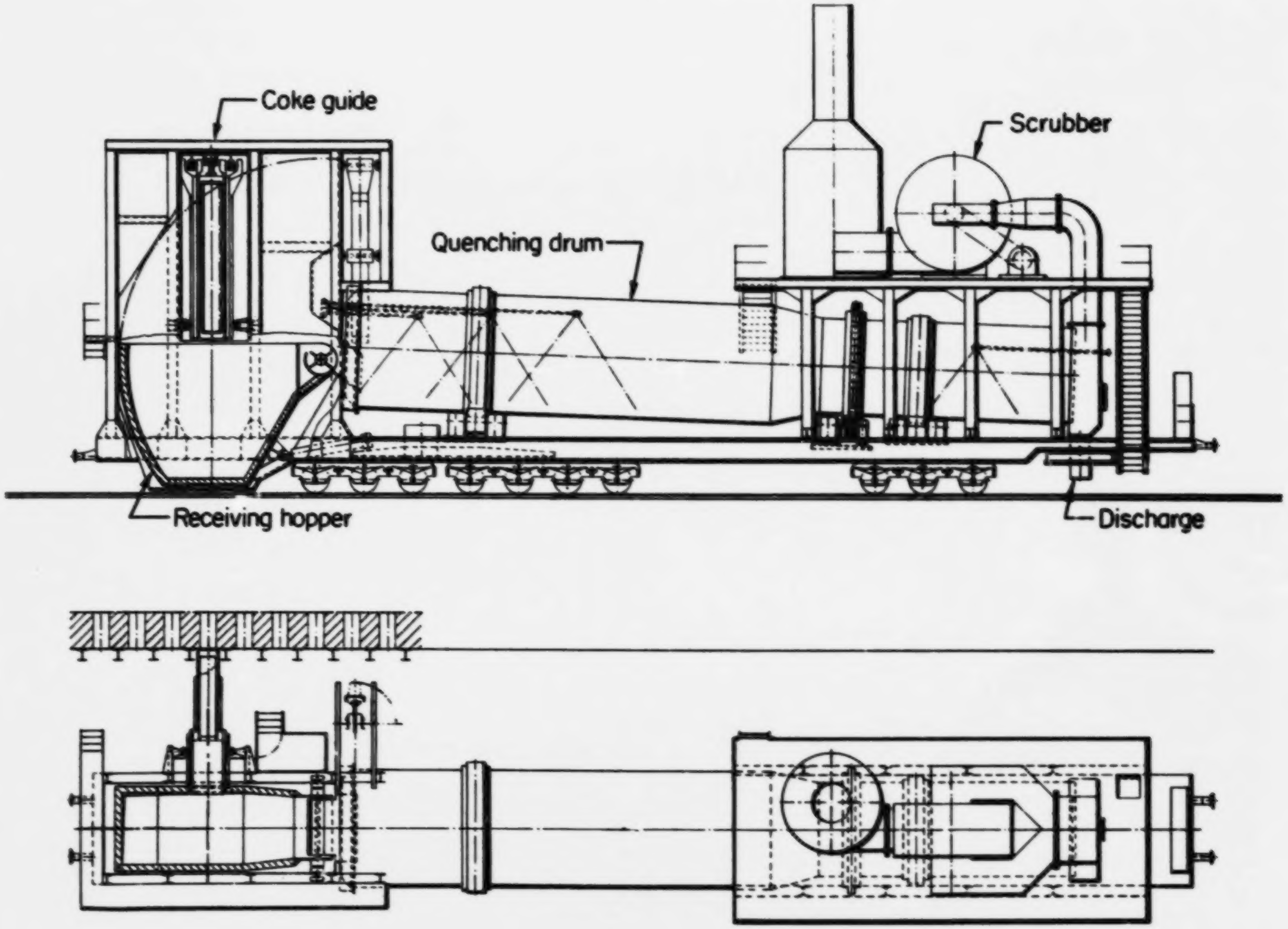

Coke guide
Scrubber
Quenching drum
Receiving hopper
Discharge

FIGURE III-32. H. KOPPERS INTEGRAL CLOSED PUSHING SYSTEM WITH CONTINUOUS QUENCHING DRUM

Source: Heinrich Koppers GmbH.

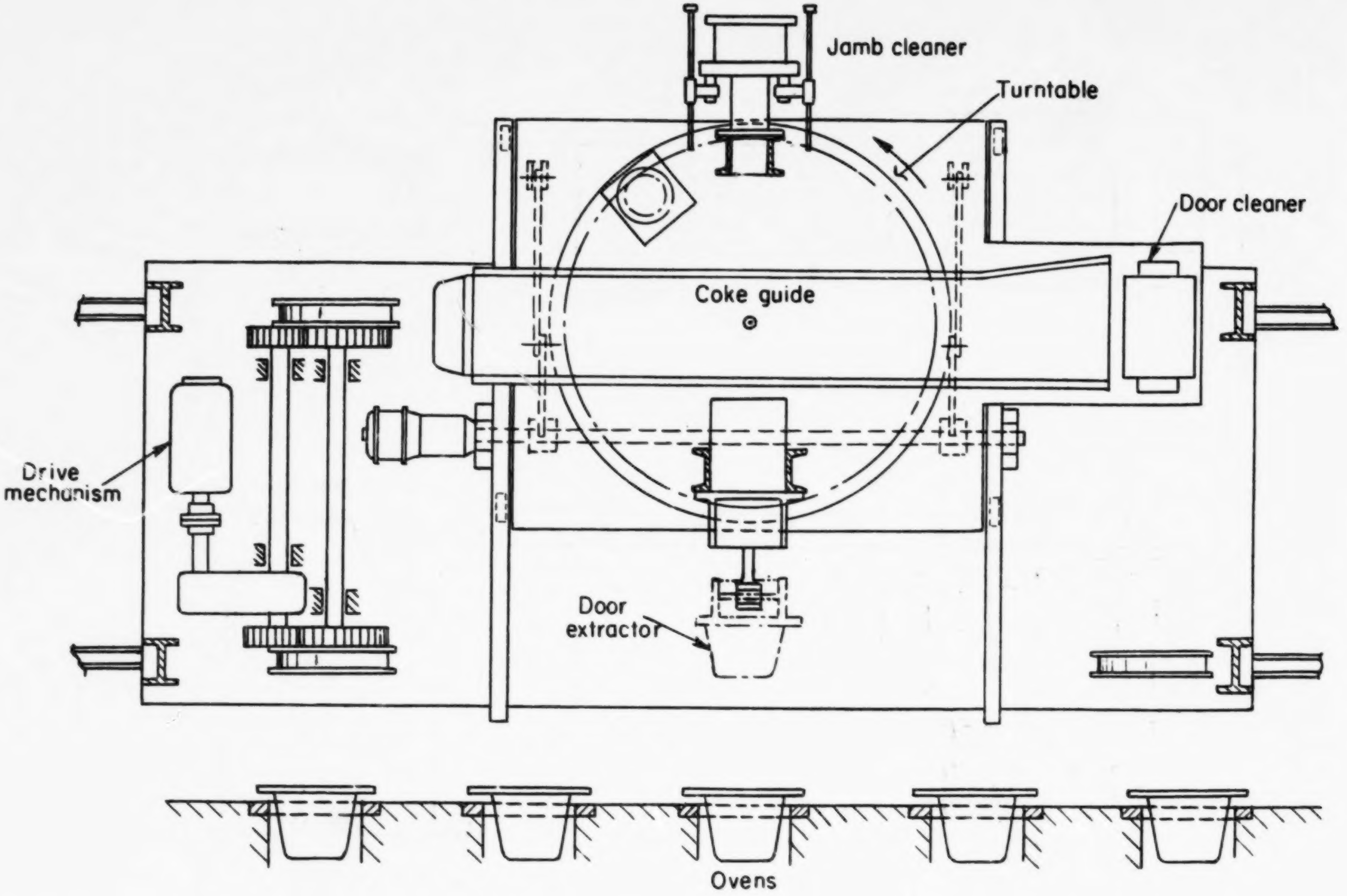

Jamb cleaner
Turntable
Door cleaner
Coke guide
Drive mechanism
Door extractor
Ovens

FIGURE III-33. HEINRICH KOPPERS ONE-SPOT DOOR MACHINE, COKE GUIDE, AND DOOR AND JAMB CLEANER

Source: German Patent No. 1,225,142

A third significant design for the controlled pushing and quenching of coke has been proposed (but not installed) by Firma Carl Still. There are several variants of the Still approach, but in the principal one (illustrated in Figure III-34), coke is pushed into a closed externally cooled transfer box that is equipped with draft and gas-cleaning equipment. No steam is raised within the transfer box; it behaves only as a closed hot-coke car. It is arranged across instead of along the coke-side trackage so that it need not be moved to accept the entire push.

Coke pushed into the transfer box is then taken by the box to a surge hopper, which is refractory lined and arranged for shrouded transfer of the hot coke. From the surge hoppers(s), the coke is fed continuously onto a traveling grate where it is continuously quenched and then released to conveyor belts.

There are other versions of the Still approach, but its main principle is the use of a closed, stationary transfer car to receive the push with positive emissions control. Like the Hartung and Kuhn hood or the Koppers door machine and receiving hopper, the Still transfer box cannot cope with a green push because the accompanying rush of smoke and flame would overload the emissions-control system, if not the enclosure itself.

Of the three prominent approaches for elimination of pushing emissions, only one is independent of quenching arrangements. The others, which incorporate controlled quenching performed continuously, may require extensive alteration of existing coke plants, or may even be developed primarily for incorporation into wholly new coke plants. The probability that pushing and quenching may someday be closely combined affects consideration of both problems, and means that some plants may not be able to accept a combined system at first.

Quenching of Hot Coke

Freshly pushed coke, at an average temperature well above 2000 F, is taken to a quenching station in the hot-coke car. At the quenching station, a controlled amount of water is sprayed on the coke to cool it to handling temperatures, typically below 200 F. This quenching operation ends with delivery of the coke (now slightly damp) to the sloping wharf from gates opening in the side of the hot-coke car.

Apparatus and Operations

The hot-coke car has a sloped bottom, inclined sufficiently so that excess quench water will drain quickly and so that the coke will slide freely out of the car and onto the coke wharf (which is sloped to match). During quenching, this entire sloped section, containing the incandescent coke, is placed within a large chimney called the quenching tower. The quenching tower is equipped with water-spray nozzles, a sump to catch the excess water that drains, and a reservoir (usually at the top) for measurement of the water required for each quenching cycle. Between quenches, water is pumped from the sump into the reservoir until a float valve closes to signify that the desired amount of water is present. During the quench itself, the water flows from the reservoir into the distributor nozzles by gravity. Figure III-35 shows the general arrangement of the tower, sump, reservoir, hot-coke car, and chimney in a typical quenching system.

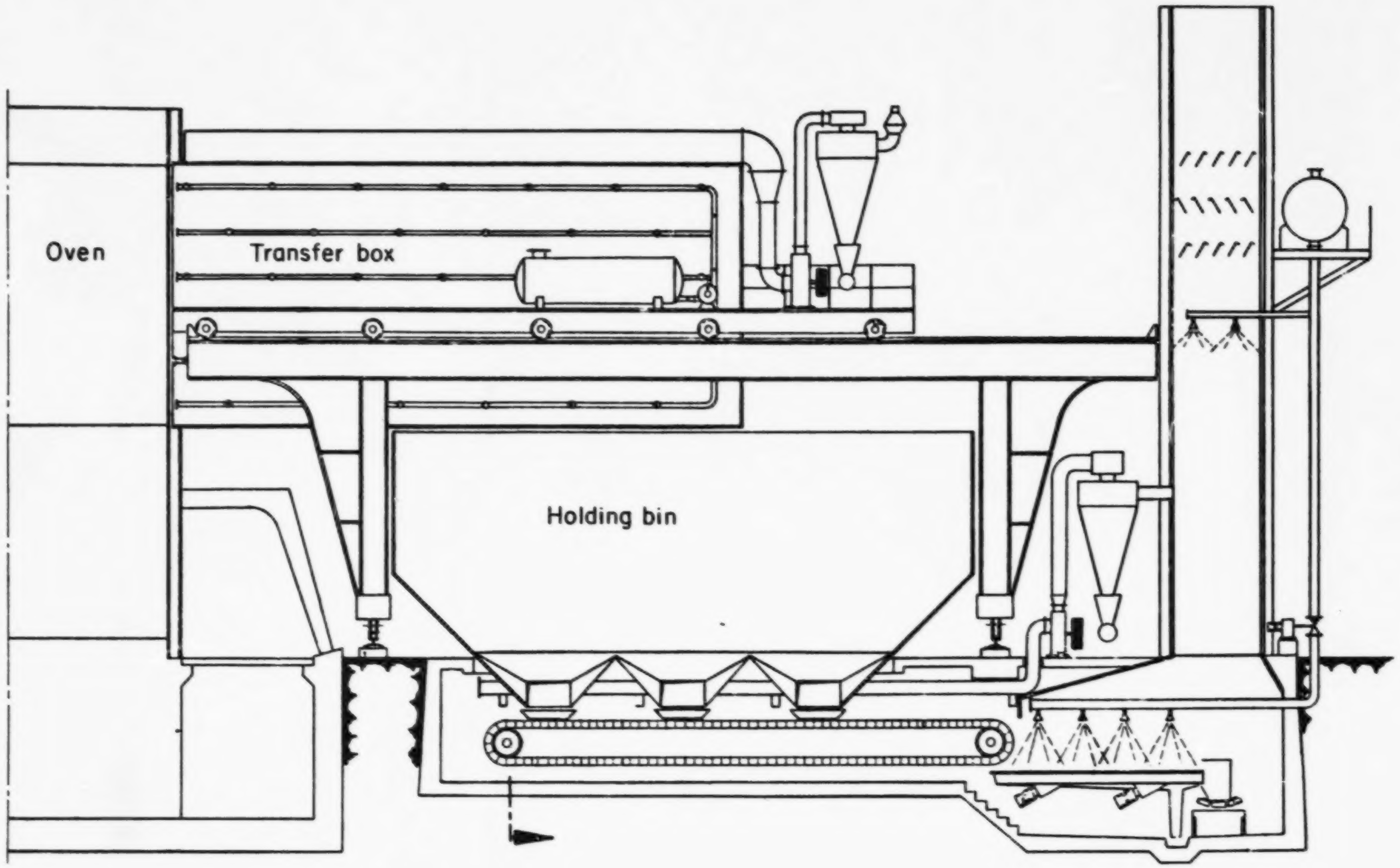

Oven
Transfer box
Holding bin

FIGURE III-34. PROPOSED ENCLOSED COKE RECEIVER AND GRATE-QUENCHING SYSTEM DESIGNED BY FIRMA CARL STILL

Source: German Patent Applications Nos. P 18 12 383.6 and P 19 28 866.5

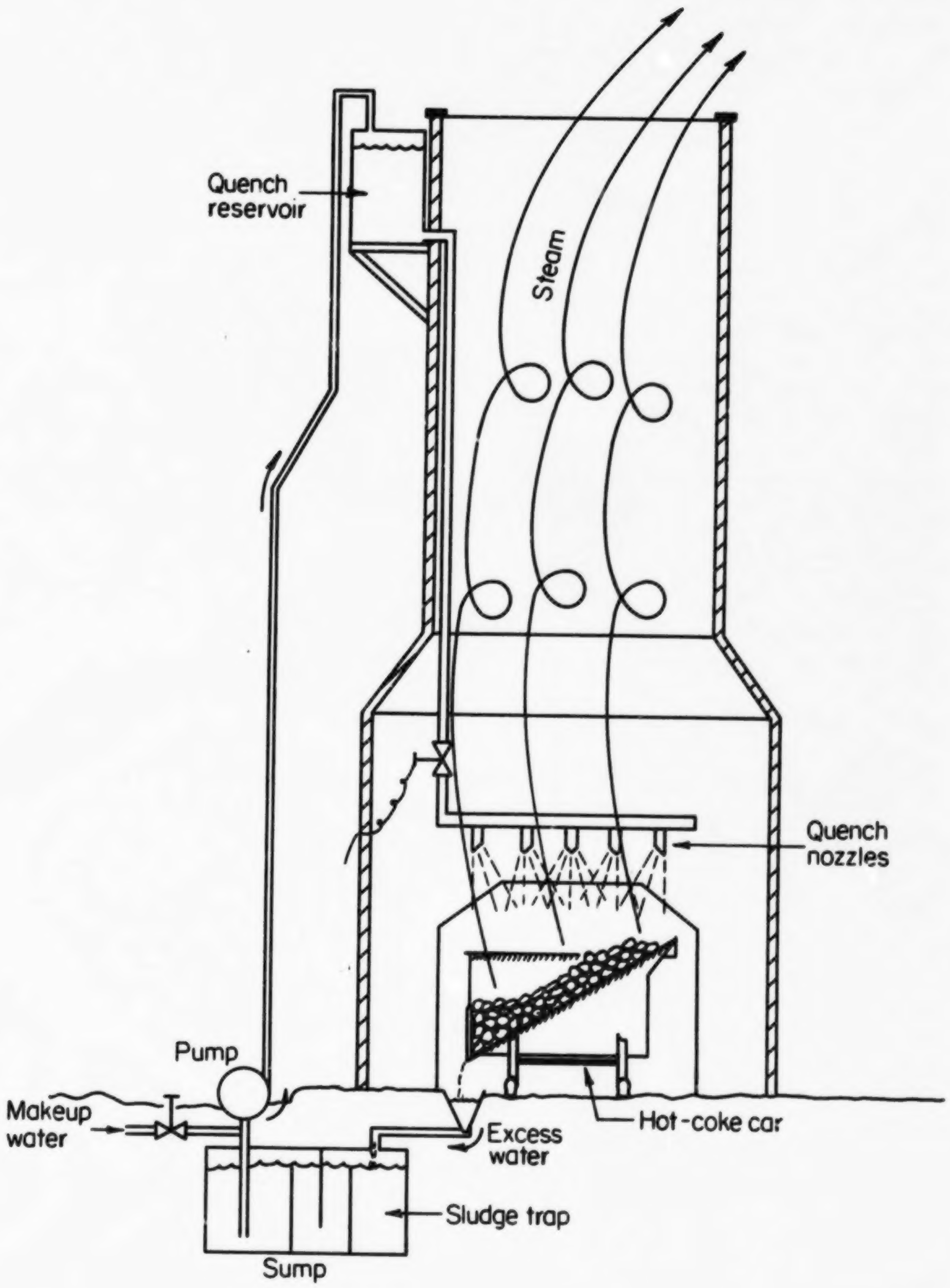

Quench reservoir
Steam
Quench nozzles
Pump
Makeup water
Excess water
Hot-coke car
Sludge trap
Sump

FIGURE III-35. TYPICAL COKE-QUENCHING SYSTEM

About once every 7 seconds, day and night, an oven of hot coke (typically 12 to 14 tons) is quenched somewhere in the United States. At this time, about 4,000 gallons of water is dumped on the coke, and about half of this water is evaporated in a tremendous rush of steam.(7) The chimney design of the tower causes the plume of steam to rise high into the atmosphere, where it dissipates or turns to rain and falls back over a wide area.

Emissions

Two kinds of emissions accompany the quenching of coke. Fine coke breeze, formed during the push and settling in the hot-coke car, is raised into the plume of quenching steam by the draft from steam formation. In addition, more breeze is formed as water is flash-evaporated within the coke itself. Accordingly, the rising column of white vapor is not so clean as it looks, and dust or grit of sizes ranging from 0.05 inch on down to micron sizes is carried aloft. This dust or grit may partially settle out on plant property, but some of it escapes.

The second kind of emission has received much less engineering attention. According to the Making, Shaping, and Treating of Steel, 8th Edition,

> "Most modern plants quench with contaminated water as there seems to be no other practical method of disposal of these waters. It is therefore necessary to design the quenching station in such a way that all such waters can be recirculated until evaporated."

This situation is changing rapidly as coke-plant managers recognize the futility of exchanging contaminated water for contaminated air. Over the last few years, many plants have disconnected the lines that used to carry dirty water to the quenching sump. The most likely emissions from contaminated water used in quenching are ammonia and phenol vapors.

Alleviation

The alleviation of emissions arising from quenching with contaminated water is best obtained by a change of practice. Recent advances in waste-water treatment technology, together with actual construction of water-treatment plants at steelworks, have given coke-plant managers an alternative to quenching with waste weak liquor. Little is known about the possible buildup of contaminants in quench water from uncontaminated sources, but any substance leached by the water from the coke could be accumulated in the quenching sump. Quench waters should be studied as a possible hidden emissions source, and if necessary, quench sumps should be bled or blown down to control accumulation of materials that may become air pollutants.

The alleviation of fine breeze, or grit, has been developed in the U. S., the U. K., and Continental Europe. The approach has been mainly to interpose baffles of one form or another between the rising column of steam and the open sky. The baffles, usually wetted, either catch or deflect most of the particulates. Other aspects of grit-emissions control include (1) design of plenums or venturiform sections into quench towers to provide a zone of pressure drop, (2) inclusion of offsets to force a change of direction, (3) maximization of tower cross section to cut steam velocity, (4) shrouding around the hot-coke car to minimize the inspiration of air into the chimney by the rising steam, and (5) back-spraying above the baffles (or in a baffleless tower) to try to catch some of the grit. Highly simplified drawings typifying these approaches are shown for purposes of illustration in Figure III-36, and some proprietary alignments are indicated.

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(7) Fullerton, R. W., "Impingement Baffles to Reduce Emissions From Coke Quenching", J. Air Pollution Control Association, 17 (12), 807-809 (1967).

Baffles placed in quench towers range from a single course of redwood placed near the top of the chimney section to a double course of stainless steel wedge-wire screen louvers arranged directly above the hot-coke car. It would be hard to imagine a greater variety in design. Some variants include: (1) use of baffles made of a thermosetting plastic which has electrostatic attracting properties for dry dust, (2) arrangement of baffles in flat, lapped, staggered parallel, chevron, or crossed form, (3) use of a wire mesh supporting a layer of large coke pieces instead of fixed baffles, and (4) arrangement of baffles in a single or double incline forming a cascade for water sprayed from above. Figure III-37 illustrates some baffle systems advocated by major U. S. and European coke-plant builders. Limited measurements have indicated that all antigrit tower/baffle systems have been effective, but there has been no comprehensive comparison.

Dry quenching of coke, usually based upon circulation of unreactive gases through the coke and then through a cooling system, has been advocated in the United Kingdom and on the Continent, but not as yet in the United States. The usual argument favoring dry quenching is based on recovery of useful energy. Control of coke moisture, less coke breakage, and fewer emissions are cited as valuable side effects. Given that emissions from wet-quenching towers can be controlled with modest new investments in baffling or design changes, the appeal of dry quenching is not greatly increased by the current interest in control of air pollution. Among the builders of coke ovens, even those who are developing new and sophisticated pushing systems for enclosed operation, dry quenching is not an object of development effort. Battelle did not study the air-pollution aspects of dry quenching in detail because the high cost of capital (higher in the U. S. than in Europe) would seem to block industry acceptance of dry quenching in the U. S. as long as wet quenching is tolerable.

Miscellaneous Problems and Opportunities

Attention will be given here to the concepts of total and partial enclosure of coke ovens and to some aspects of problems that can arise when turbine exhausters at the coke-oven gas booster station fail.

Total Enclosure

From time to time, it is suggested that coke should be produced within a building instead of out in the open air. When this suggestion is made, coke producers usually raise the issues of heat loads and fumes to be drawn out of such a building. If a hypothetical example is taken, it is possible to examine the proposal and its difficulties objectively but in a preliminary fashion.

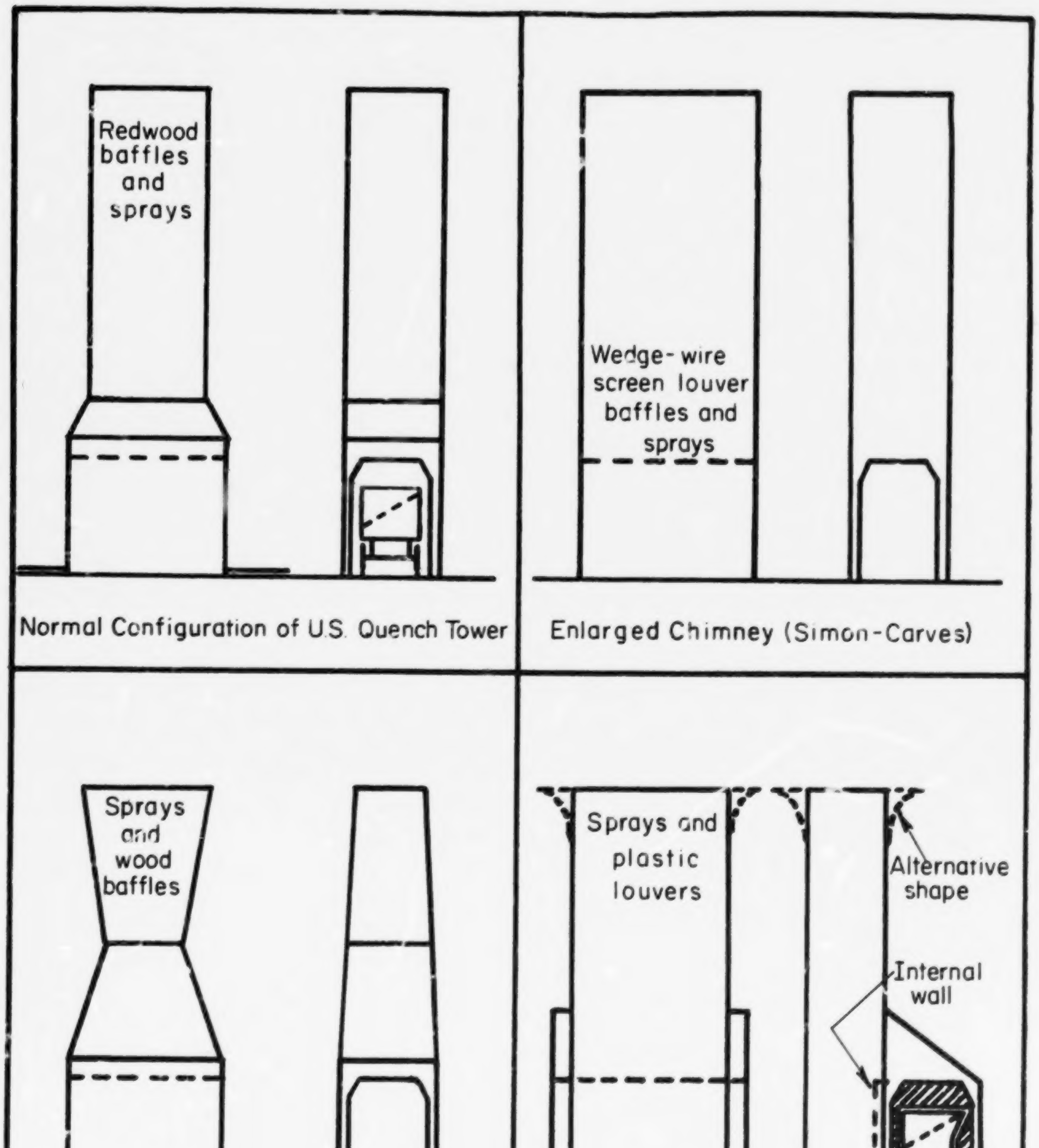
Redwood baffles and sprays
Normal Configuration of U.S. Quench Tower
Wedge-wire screen louver baffles and sprays
Enlarged Chimney (Simon-Carves)
Sprays and wood baffles
Venturi Chimney
(Heinrich Koppers GmbH.)
Sprays and plastic louvers
Alternative shape
Internal wall
Offset Chimney, Shrouded Car Entry
(Firma Carl Still)

FIGURE III-36. SOME QUENCH TOWERS DESIGNED TO MINIMIZE GRIT EMISSIONS

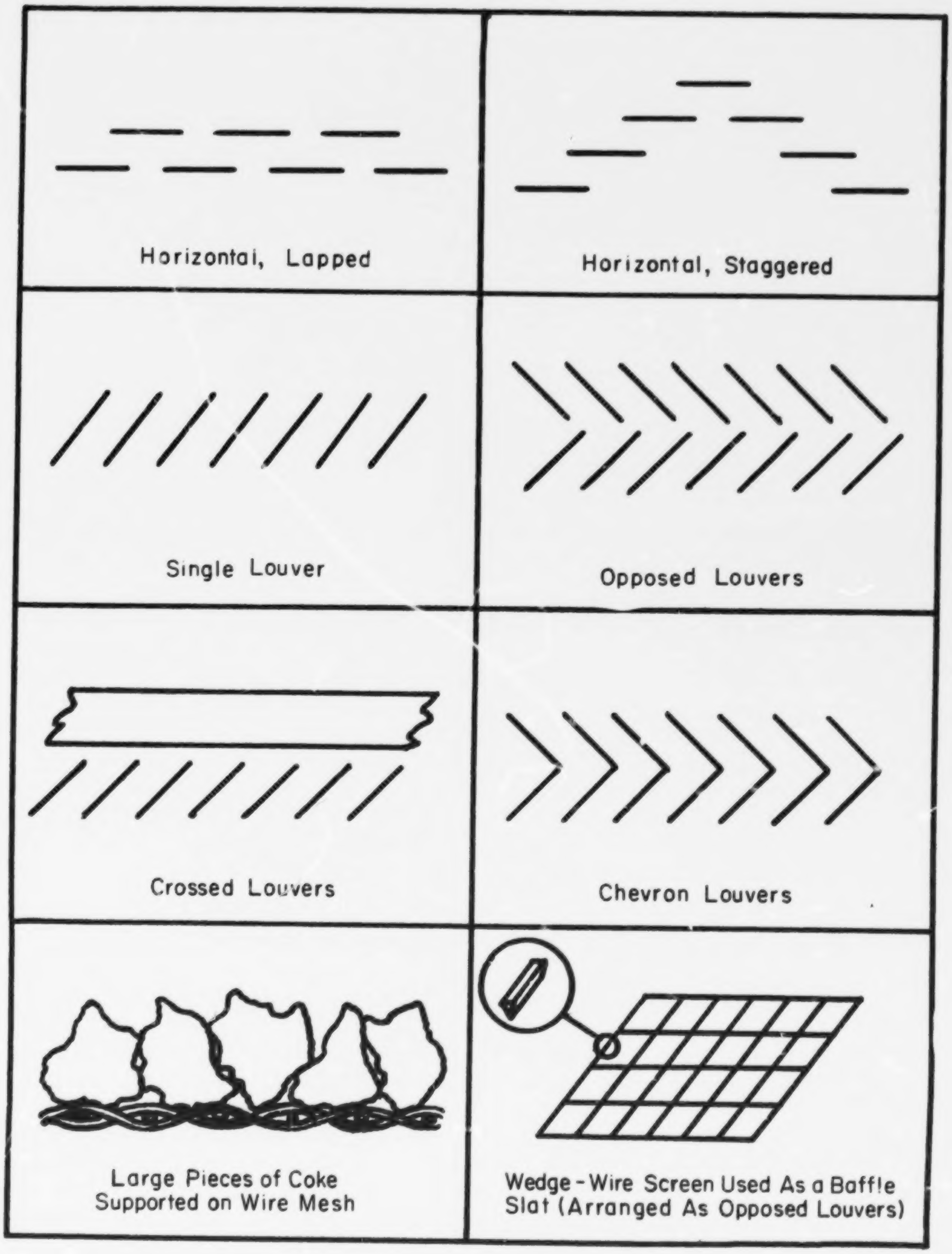
Horizontal, Lapped
Horizontal, Staggered
Single Louver
Opposed Louvers
Crossed Louvers
Chevron Louvers
Large Pieces of Coke Supported on Wire Mesh
Wedge-Wire Screen Used As a Baffle Slat (Arranged As Opposed Louvers)

FIGURE III-37. SOME ARRANGEMENTS OF BAFFLES

Suppose that a battery of 80 modern, 6-meter ovens is to be fully enclosed. The dimensions are as follows:

Oven Dimensions

Length	52 feet door to door
Height (of Coal)	19-1/2 feet from sole
Width	20 inches wall to wall

Battery Dimensions

Width Overall	160 feet
Height Above Grade	50 feet (coal bunker sticks up higher)
Length Overall	350 feet (quench tower is outside)
Occupied Volume	800,000 ft^3 (bricks, pipes, steel, and coal)
Gross Volume	2,800,000 ft^3 (air space about 2 million ft^3)

For the enclosure of this battery, the following assumptions are made:

(1) Several dozen men will be working inside the building.

(2) Ports will be provided for the hot-coke car to exit and reenter, and for no other operating purpose.

(3) Operation is on a 16-hour cycle, with production of 3500 tons of coke per day from 5000 tons of coal.

(4) Internal smoke controls are such that only thermal considerations determine the amount of exhausting required.

Given the above conditions, plus the information already known about thermal losses during coking, one may construct the following argument. First, the leakage of heat from the battery into the air is assumed to be about 13 percent of underfiring energy.$^{(8)}$ This amounts to about 140 Btu per pound of coal coked. The only other heat released is radiation and convection from the glowing coke as it is pushed, but for the present purposes it is presumed that a closely contained pushing system is used, such that heat release is indirect and is limited to only 10 Btu per pound of coke before the hot-coke car leaves the building. The total heat load released within the building, therefore, is $\left\{\begin{array}{c}\text{battery leakage}\\ 5000 \times 140 \times 2000\end{array}\right\} + \left\{\begin{array}{c}\text{coke discharge}\\ 3500 \times 10 \times 2000\end{array}\right\}$ = 1470 million Btu per day. Allowing for the fact that about half of the air in the building must absorb all of the heat (the other half, near the ground, never becomes warmed), the thermal load is about 1470 Btu per day per cubic foot of effective volume.

The amount of exhausting to be done from such a building may now be calculated from the allowable temperature rise. Given summer conditions which may take the ambient temperature to 90 F, engineering for a maximum rise of 10 degrees seems appropriate. The Btu equivalent is 10 degrees x 0.25 Btu/lb x 0.075 lb air/ft^3 = 0.19 Btu per cubic foot allowable in the air which becomes heated. Thus the building must be exhausted 1470/0.19 = 7740 times per day, or more than five times each minute. The requisite airflow, assuming efficient drafting and proper positioning of exhaust ports in the roof, is about 11 million cubic feet per minute.

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(8) Ess, T. J., "The Modern Coke Plant", Iron and Steel Engineer, 25, No. 1, C-3 to C-7 (January, 1948).

The above calculations (which probably contain errors in some of the assumptions) show that the airflow to handle the heat load is large, but technically possible to obtain. However, all of the exhaust air from such a building must be cleaned. If it is recognized that fail-safe exhausting (to protect workers) requires at least two blowers and at least two independent air-cleaning systems, the concept of total enclosure and unified cleaning/exhausting begins to appear questionable, both economically and from an engineering viewpoint. It is now appropriate to point out that the original assumptions included the idea that suitable emissions controls would be provided inside the building, so that exhausting requirements were determined by heat loads alone. Under such conditions, a building system of the type usually mentioned becomes a huge add-on to an otherwise well-equipped coke plant.

In addition to the foregoing engineering aspects, there is uncertainty about the environmental hazards to workers in the building. Certainly much study would have to be given to aspects of health (noxious gases) and safety (explosion hazards) before workers could be allowed to work in such an enclosure.

Partial Enclosure

Not so impractical is the alternative of providing careful and nearly total enclosure over the coke side of the battery, such that the coke is pushed and carried to the quencher within a virtual tunnel. This concept was raised within Battelle, and has also been considered by the AISI and the Dravo Corporation. Such a partial enclosure could be made manless if the wharf, door and guide machine, and hot-coke car were automated. Alternatively, the tunnel could be exhausted from one end through a smaller and simpler gas-cleaning system, or conceivably (with dedusting) into the underfiring air supply. Such an approach would combine well with a revised pushing and quenching system such as the ones proposed by Heinrich Koppers and Carl Still. The principal objection to an unmanned tunnel is the risk based upon failure of automatic equipment. The principal objection to a manned tunnel is human exposure to an uncertain and potentially hazardous environment.

Abnormal Operations

When the turbine exhausters at the coke-oven gas booster station fail, the pressure drop of the entire by-product system blocks the flow of coking gases from the ovens. Because this blockage must be relieved promptly, the usual practice is to duct the raw gases to an emergency stack located near the primary coolers. The amount of emission resulting from complete bypass of the by-product system is substantial.

At least one U. S. plant has been equipped with a different kind of emergency stack which ignites and thoroughly burns raw gases if and when there is a booster breakdown. With this provision, the results of an exhauster failure (which may range from a few minutes to several hours) or of other serious trouble in the by-product system are no worse than the flaring of waste gases from an oil refinery. There appears to be little reason to seek a more sophisticated control, because use of the emergency stack is rare and becoming rarer.

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SECTION IV

NEW COKING PROCESSES

The technology of making blast-furnace coke by other than the conventional slot-oven process is described in this section. The designation "new coking processes" is used in the context that these processes are now being used in attempts to make high-strength blast-furnace coke at high finishing temperatures (up to 1900 F). Frequently these new processes use equipment or unit operations that are in themselves old.

The section begins with definitions of some terms as used in this report, and a brief discussion of the evolution of continuous processes and some of their technical elements. Emphasis throughout is on the relationship of these processes to their potential for lowering air pollution from the manufacture of blast-furnace coke.

Definition and Explanation of Terms

Metallurgical coke is a generic term referring to a porous, carbonaceous, coal-based residue that is used as a reductant in metallurgical processes. The strength and other characteristics of metallurgical coke can vary, depending on the metallurgical processes in which it is used. Because the term can be ambiguous, it is not used in this discussion of new coking processes.

Blast-furnace coke is the strong and porous carbonaceous residue resulting from the high-temperature distillation of selected grades of bituminous coals. Blast-furnace coke in its normal lump form has the strength, abrasion resistance, and other characteristics that allow it to be used successfully in blast furnaces. At the present time, all blast-furnace coke is made in conventional slot-type by-product ovens or (to a very limited degree) in beehive ovens, both of which are batch-type processes conducted in outdoor equipment.

Chemical coke is weaker than blast-furnace coke, but is acceptable as a reductant in some chemical processes. This term is only of interest for the present purposes because developers of some new coking processes are presently selling coke to chemical operations. Some developers of continuous coking processes believe that their coke has sufficient strength to be used in blast furnaces.

Formcoke is the sized and shaped product of most of the new continuous coking processes. It is made by the successive steps of (1) blending together powdered coal and/or other carbonaceous materials, usually with a binder; (2) briquetting, pelletizing, or otherwise mechanically shaping and pressing the powdered materials into consistent sizes and shapes; and (3) heating the briquettes or pellets to devolatilize the formed pieces. A photograph of several samples of different formcoke products is shown in Figure IV-1.

Pitch, or coal-tar pitch, is the viscous residue resulting from the fractional distillation of the liquid by-products from coking of coal. Pitch is the preferred binder for

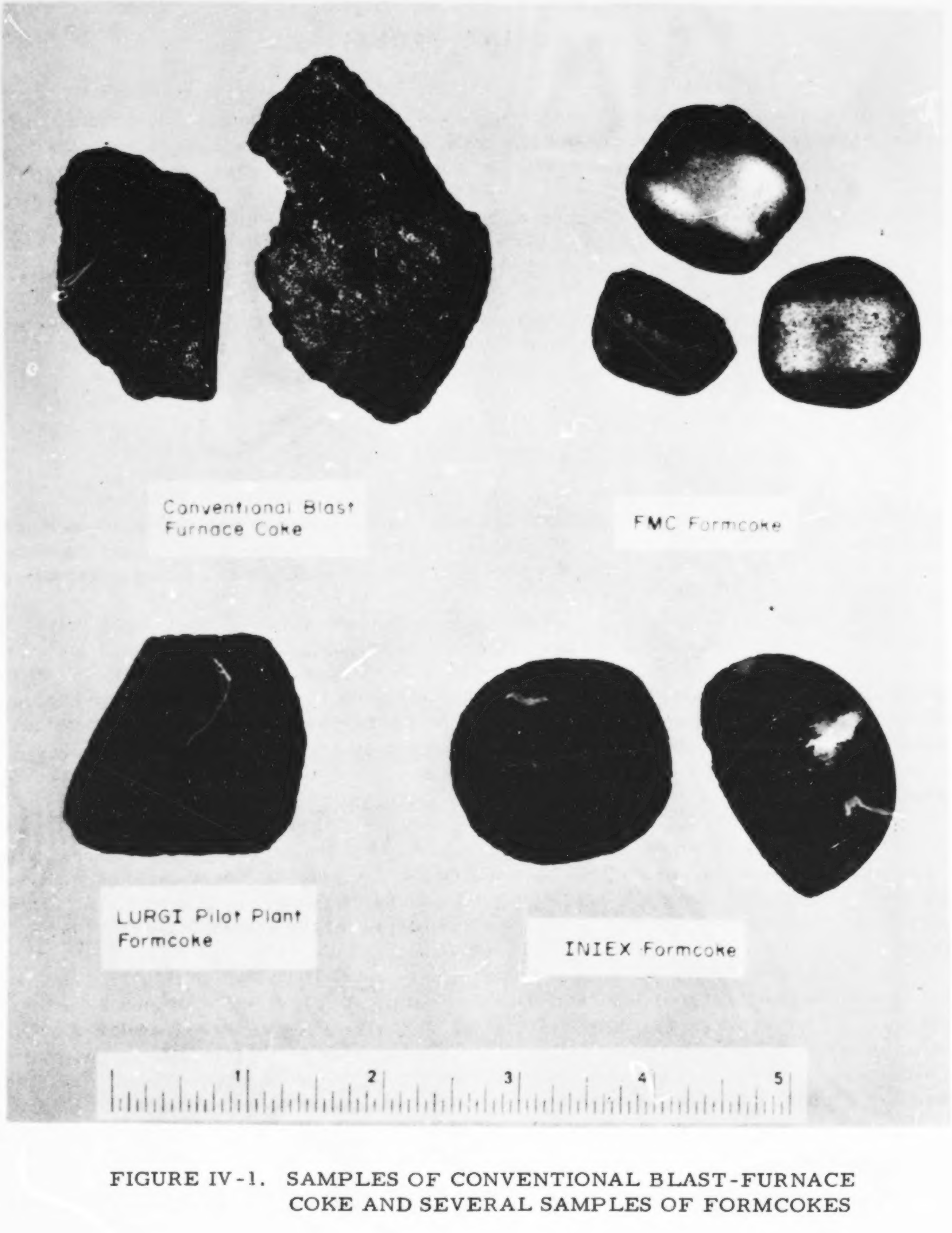

Conventional Blast Furnace Coke
FMC Formcoke
LURGI Pilot Plant Formcoke
INIEX Formcoke
1
2
3
4
5

FIGURE IV-1. SAMPLES OF CONVENTIONAL BLAST-FURNACE COKE AND SEVERAL SAMPLES OF FORMCOKES

almost all formcoke processes. During the final high-temperature coking stage of most formcoke operations, the pitch yields a coke which cements the carbonaceous aggregates into a strong product.

Char, or semicoke, is the partly devolatilized carbonaceous product derived from low-temperature carbonization of coal. In some formcoke processes, char is a primary constituent along with coal or pitch.

Caking coal has the natural property of particle adherence as a result of heating. The use of some caking coal is a requirement in some formcoke processes. The conventional slot-oven process requires caking coal. As a general rule, caking coals command a premium price over noncaking coals.

Evolution of Continuous Coking Processes

The development of continuous coking processes has been a challenge to many inventors, entrepreneurs, and companies for over 60 years. The first period of activity in this direction was during the era when almost all home heating was done by burning bituminous coals. The burning of bituminous coals on home grates and in furnaces resulted in much smoke, primarily because of the high volatile content of the coal. In an effort to produce a smokeless fuel (partly devolatilized coal or semicoke) in a form acceptable for household use, and to recover the valuable by-products from coal coking in the manner that made the slot process so economically attractive, many attempts were made to develop low-temperature, continuous coking processes operating below 1100 F. To a degree, some of these processes were successful in Europe where there was a stronger market for both the smokeless fuels and the by-products. In the United States, these development efforts were not so successful because space heating with oil and gas displaced coal-fired home heating, and because the low-temperature tar by-products were different and less valuable than the by-product tars from high-temperature slot ovens. It has been estimated that in the United States, up to $50 million was spent between 1920 and 1930 in unsuccessful low-temperature, continuous coking processes. Lack of success was not technological but economic – the cost of processing could not be borne by the price that the products could command in the open market. The successful exception was the Disco process which converted low-value coal screenings to a lump smokeless fuel. The unique nodulizing feature of the Disco process is a prominent feature of Consolidation Coal Company's (Pittsburgh, Pa.) formcoke process. This process is described later.

Interest in the low-temperature continuous coking attempts of the past lies in the fact that the "new" coking processes of today are high-temperature extensions of the processes of the past. An excellent review of low-temperature continuous coking is available in the book The Chemistry of Coal Utilization, published by John Wiley & Sons (1963).

The main differences between the new coking processes and those of the past lie in (1) the active development that is in progress to make formcoke of blast-furnace quality and (2) the application of modern heating methods and process technology. Examples of two modern heating methods used in new continuous coking processes are fluidized-bed charring units and circulating hot-sand heaters. A similarity between old and new processes exists, in that both collect low-value by-products from the low-temperature (early) stages.

Factors that have stimulated the present-day interest of both European and American developers in continuous coking processes are:

(1) Desire to use cheaper noncaking coals as charge material for making blast-furnace coke

(2) Expectation that the substitution of formcoke of constant shape and size for lump slot-oven coke will open a new avenue to improve the performance of blast furnaces

(3) Recognition that the air-pollution problems associated with slot-oven coking can be brought under control only at an increase in the cost of producing blast-furnace coke.

(4) Need for more chemical coke, resulting in part from the diversion of coke breeze (blast-furnace screenings or fines) from sales to chemical processers to in-house use in sintering operations.

Some Technical Elements of New Coking Processes

The technology of formcoking and other continuous coking processes is varied and complex. Some of the complications to be considered in designing a new process for making blast-furnace coke include the following:

(1) Coals from different deposits or mines can, during heating, have wide variations in the amount of caking power, the amount of fluid coal that develops during the early part of the heating cycle, the amount of swelling that occurs on heating, and other factors.

(2) Blast furnaces require a strong, cohesive, massive form of coke, and cannot use fines or a friable product.

(3) Because many coals soften and may turn at least partly fluid during heating, in continuous processes the amount of fluid must be restricted to (a) prevent run-off of the fluid coal, (b) prevent adherence of the coal to the equipment, and (c) prevent slumping of the intermediate product prior to final coking.

(4) Some fluid caking coal or pitch is, however, a requirement during an early stage in the continuous process to cement the powdered chars and inert fractions in coal into a coherent mass.

(5) The rate of absorption of heat by lumps of coal or by formed briquettes is low because these materials have low thermal conductivity. The larger the size of the lumps or briquettes, the lower is the production rate of the coking unit. It is claimed by the proponents of one process that briquettes of devolatilized char and pitch can be heated at a higher rate than other char and coal mixtures.

In modern formcoke processes, the amount of fluid is controlled by oxidizing the coal prior to briquetting or by diluting the coal with char. In many processes, the partial or complete devolatilization of coal in an initial charring operation is a requirement.

The strength of the product is enhanced by (1) using a caking coal or a pitch binder, (2) increasing the pressure in the briquetting presses to use the binder more efficiently, and (3) increasing the temperature of the final high-temperature coking step.

In some processes where the materials being briquetted must be heated slowly to avoid swelling and cracking, the heating rate is controlled in carbonizers that use beds of hot sand as a heat-transfer medium. In other processes, the raw briquettes can be "shock coked" by moving the raw briquettes into a heated furnace without preheat.

In general, the various processes develop from two alternatives: (1) the heating process must be adjusted to suit the raw briquette mixture that is available or (2) the briquetting mixture must be adjusted to the heating equipment that has been selected. Although there is an exception, generally no one continuous coking process is adaptable to all possible coals. However, the range of coals that can be coked in various processes is much wider than the range permissible in the conventional slot-oven process for making blast-furnace coke. Those processes that can use a cheap noncaking coal have a potential economic advantage, unless their requirement for a caking-coal binder is unusually high.

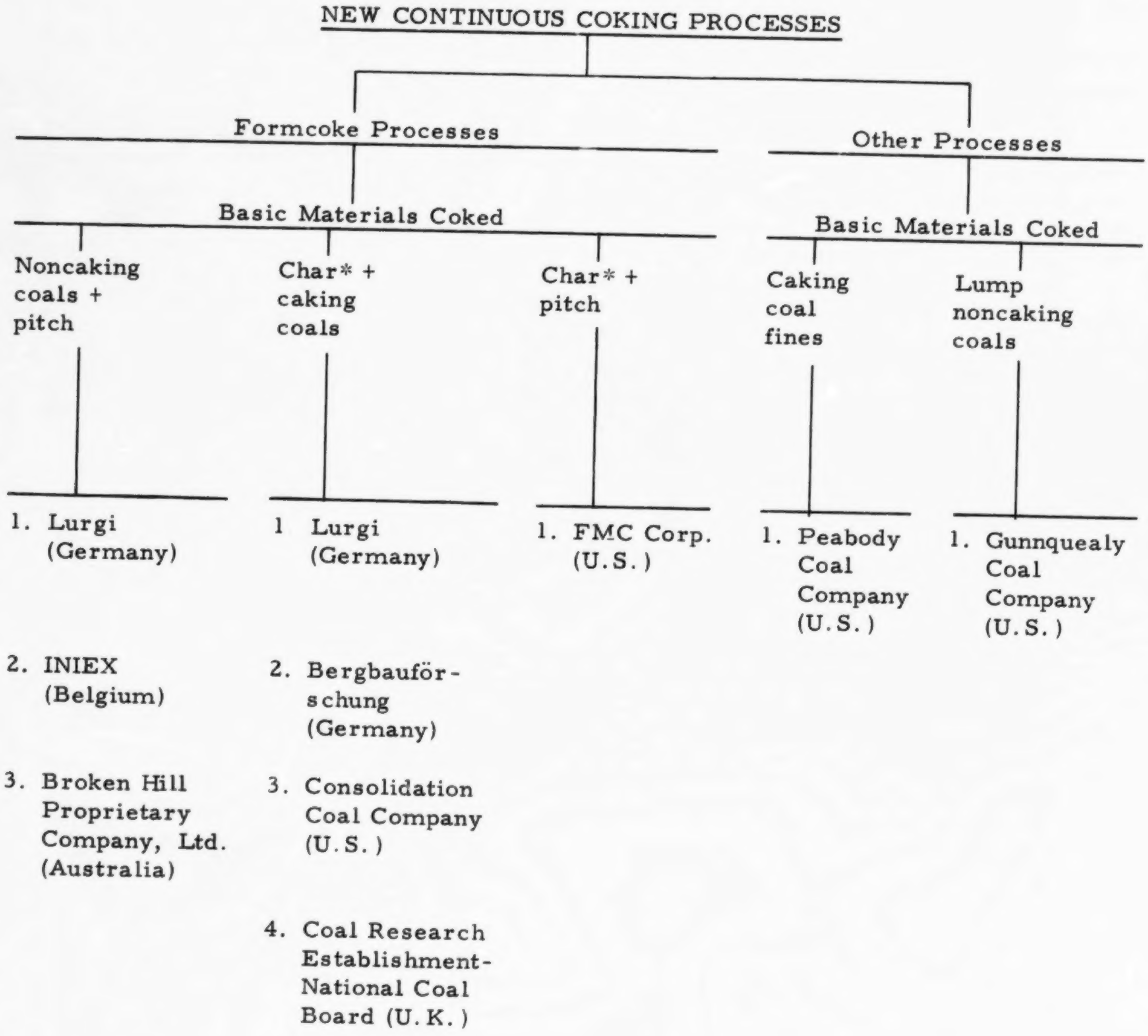
Classification and Description of New Coking Processes

The continuous new coking processes being developed with the objective of making blast-furnace coke can be classified in many ways, including classification by whether or not the product is formcoke, by the coals and materials that are coked, and by the types of equipment used. To emphasize the point that various continuous coking procedures have different requirements for coal and other raw materials, a general classification shown in Figure IV-2 is based mainly on the basic materials that are used. Also included in this figure are the names of some of the more prominent organizations associated with these processes.

In the general descriptions that follow, the emphasis is on the type, number, and combination of types of unit operations used in each process. An example of a unit operation, common to at least five continuous coking processes, is the fluid-bed charring unit used to partly devolatilize coal. This unit-operation approach lends itself to a discussion of the air-pollution control aspects of the specific unit operations associated with new coking processes.

Description of Continuous Formcoke Processes

The major research effort in progress today to develop a continuous process for making blast-furnace coke is in the field of formcoke. The idea of using a consistent and uniformly sized coke in the blast furnace has appeal. This, together with the substantial present activity in this field, has dictated that the major emphasis in this descriptive section be given to formcoke.

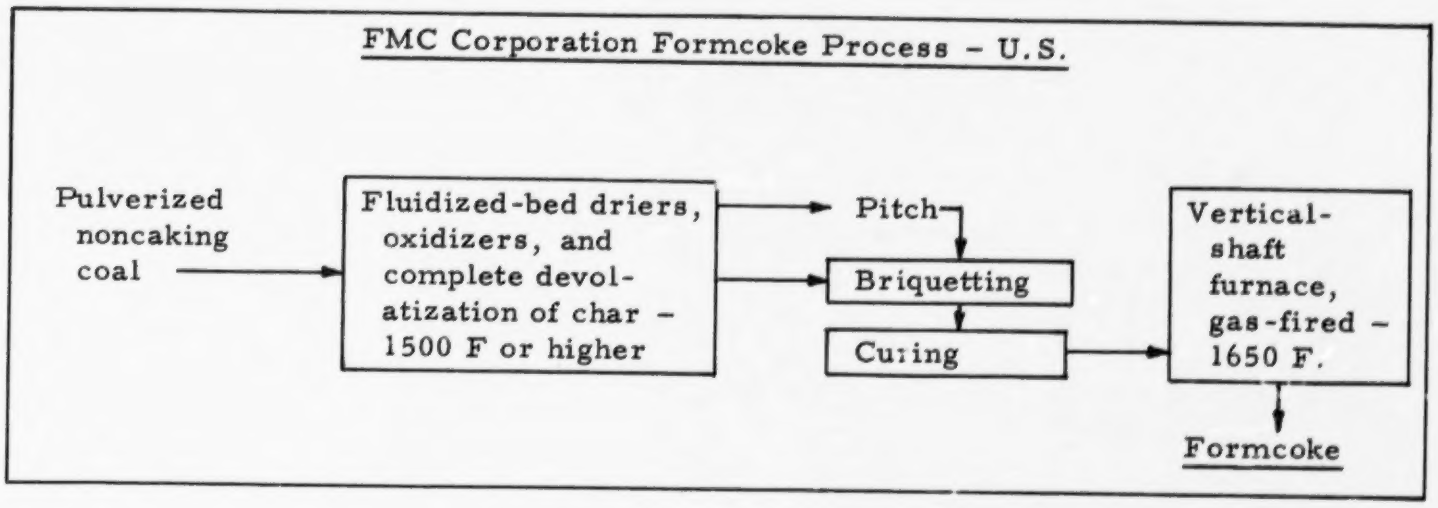

NEW CONTINUOUS COKING PROCESSES
Formcoke Processes
Other Processes
Basic Materials Coked
Basic Materials Coked
Noncaking coals + pitch
Char* + caking coals
Char* + pitch
Caking coal fines
Lump noncaking coals
1. Lurgi (Germany)
2. INIEX (Belgium)
3. Broken Hill Proprietary Company, Ltd. (Australia)
1 Lurgi (Germany)
2. Bergbauförschung (Germany)
3. Consolidation Coal Company (U.S.)
4. Coal Research Establishment-National Coal Board (U.K.)
1. FMC Corp. (U.S.)
1. Peabody Coal Company (U.S.)
1. Gunnquealy Coal Company (U.S.)

*Char can be made from caking coals, but is more easily made from low-volatile noncaking coals.

FIGURE IV-2. GENERAL CLASSIFICATION SYSTEM FOR NEW CONTINUOUS COKING PROCESSES

For the technically oriented reader, the schematic flow sheets for four formcoke processes are shown in Figures IV-3 through IV-6. Two of these processes are being developed in the United States and two are being developed in Germany.

As a simplifying procedure leading to a description of the various unit operations involved, the flow sheets for formcoke processes are next represented as a combination of unit operations in block diagram form. In the block diagrams below and on following pages, two terminal steps common to all formcoke processes are omitted. These are crushing of coal and cooling of formcoke.


FMC Corporation Formcoke Process - U.S.
Pulverized noncaking coal
Fluidized-bed driers, oxidizers, and complete devolatization of char - 1500 F or higher
Pitch
Briquetting
Curing
Vertical-shaft furnace, gas-fired - 1650 F.
Formcoke

The above block diagram illustrates FMC Corporation's formcoke process utilizing a multistage fluidized-bed charring and calcining operation prior to the mechanical forming of briquettes. A detailed flowsheet is shown in Figure IV-3. At the present time, FMC Corporation has a 200-ton-per-day demonstration plant in operation at Kemmerer, Wyoming, in which a western subbituminous coal is used as feed material. This coal is noncaking, but FMC Corporation has demonstrated on a scale of 1 ton per day that caking coals can also be used in this process.

About 2000 tons of FMC Corporation formcoke was tested in U. S. Steel Corporation's experimental blast furnace. The conclusions drawn from these tests were: (1) the high chemical reactivity of the formcoke did not result in any unusual effects in the small blast furnace and (2) at normal wind rates for this furnace, the formcoke performed at least as well as high-quality eastern coke made in slot ovens.

A substantial quantity of FMC Corporation formcoke was also given a limited trial in a full-scale blast furnace of the Armco Steel Corporation. The results of this trial were not published, but it is understood that the formcoke "did not break down at the high temperature and under the weight of the burden in the blast furnace", but that the dusting of the FMC formcoke presented problems. In general, the results of this trial were considered mixed and inconclusive.

In comparison with other formcoke processes, the FMC process has two unusual aspects. Most fluidized-bed charring units are used to remove only a fraction of the volatile matter from the feed coal, but the FMC Corporation process has a final high-temperature (about 1500 F) fluidized-bed unit that almost completely devolatilizes the char to produce an intermediate product called "calcinate". This calcinate is blended with pitch and is then briquetted to make raw formcoke shapes. The required pitch for

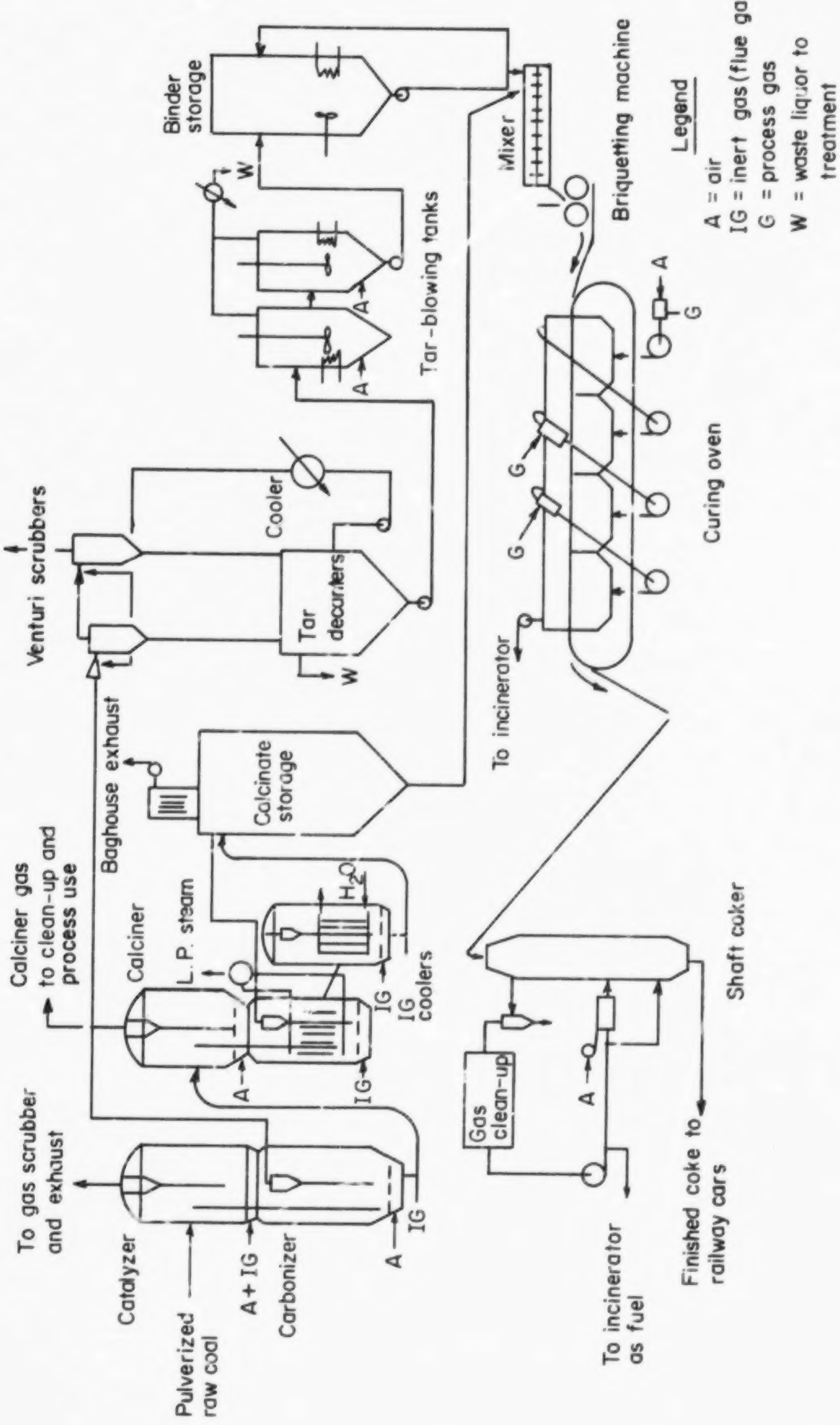

To gas scrubber and exhaust
Catalyzer
Pulverized raw coal
A + IG
Carbonizer
A
IG
Calciner gas to clean-up and process use
Calciner
L. P. steam
A
IG
IG
IG coolers
H_2O
Baghouse exhaust
Calcinate storage
Venturi scrubbers
Tar decanters
W
Cooler
Tar-blowing tanks
A
A
W
Binder storage
Mixer
Briquetting machine
To incinerator
G
G
Curing oven
A
G
Gas clean-up
A
To incinerator as fuel
Finished coke to railway cars
Shaft coker
Legend
A = air
IG = inert gas (flue gas)
G = process gas
W = waste liquor to treatment

FIGURE IV-3. FMC CORPORATION'S FORMCOKE PROCESS

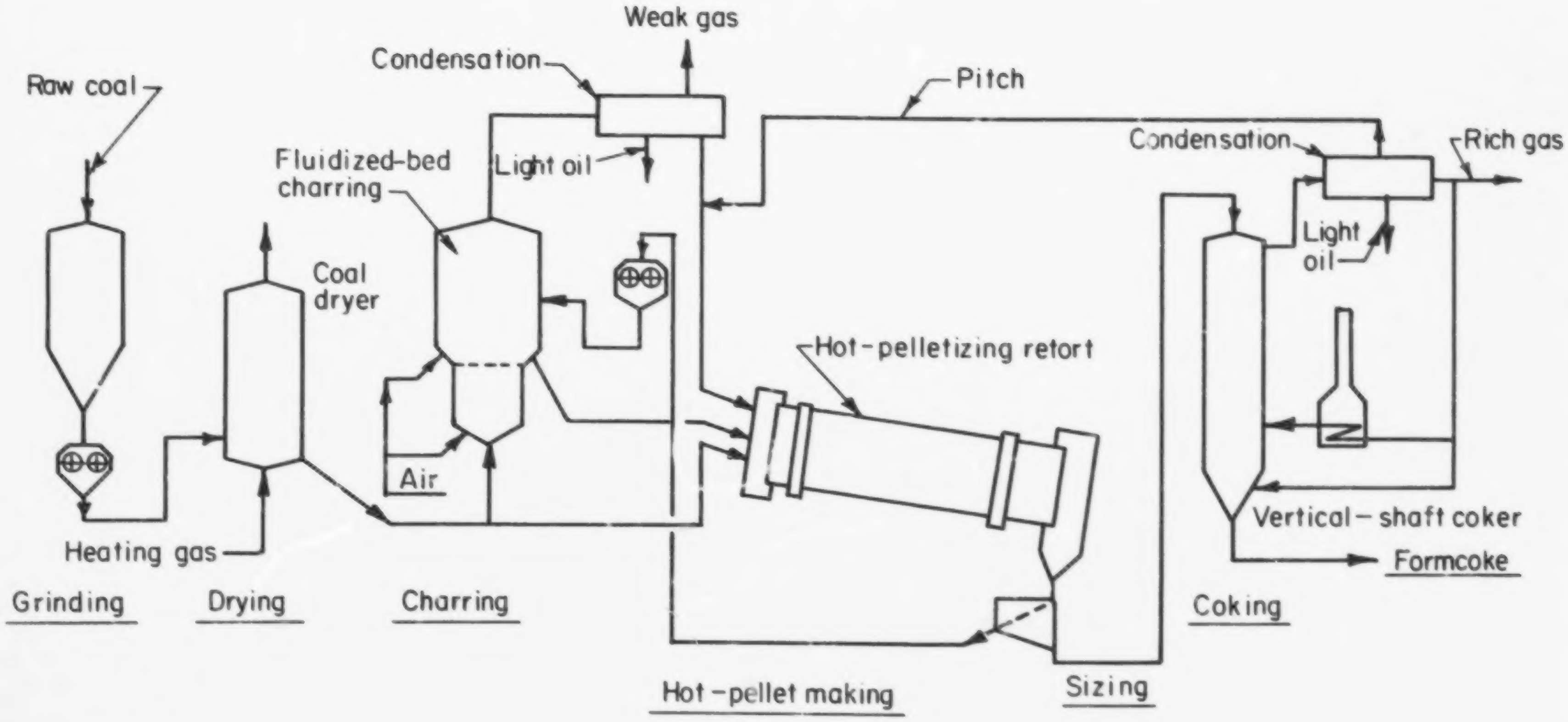

Raw coal
Heating gas
Grinding
Coal dryer
Drying
Fluidized-bed charring
Condensation
Light oil
Weak gas
Air
Charring
Pitch
Hot-pelletizing retort
Hot-pellet making
Sizing
Condensation
Rich gas
Light oil
Vertical-shaft coker
Formcoke
Coking

FIGURE IV-4. CONSOLIDATION COAL COMPANY'S FORMCOKE PROCESS (U.S.)

Hot pellets are formed in a rotating kiln.

Source: Lurgi, Germany

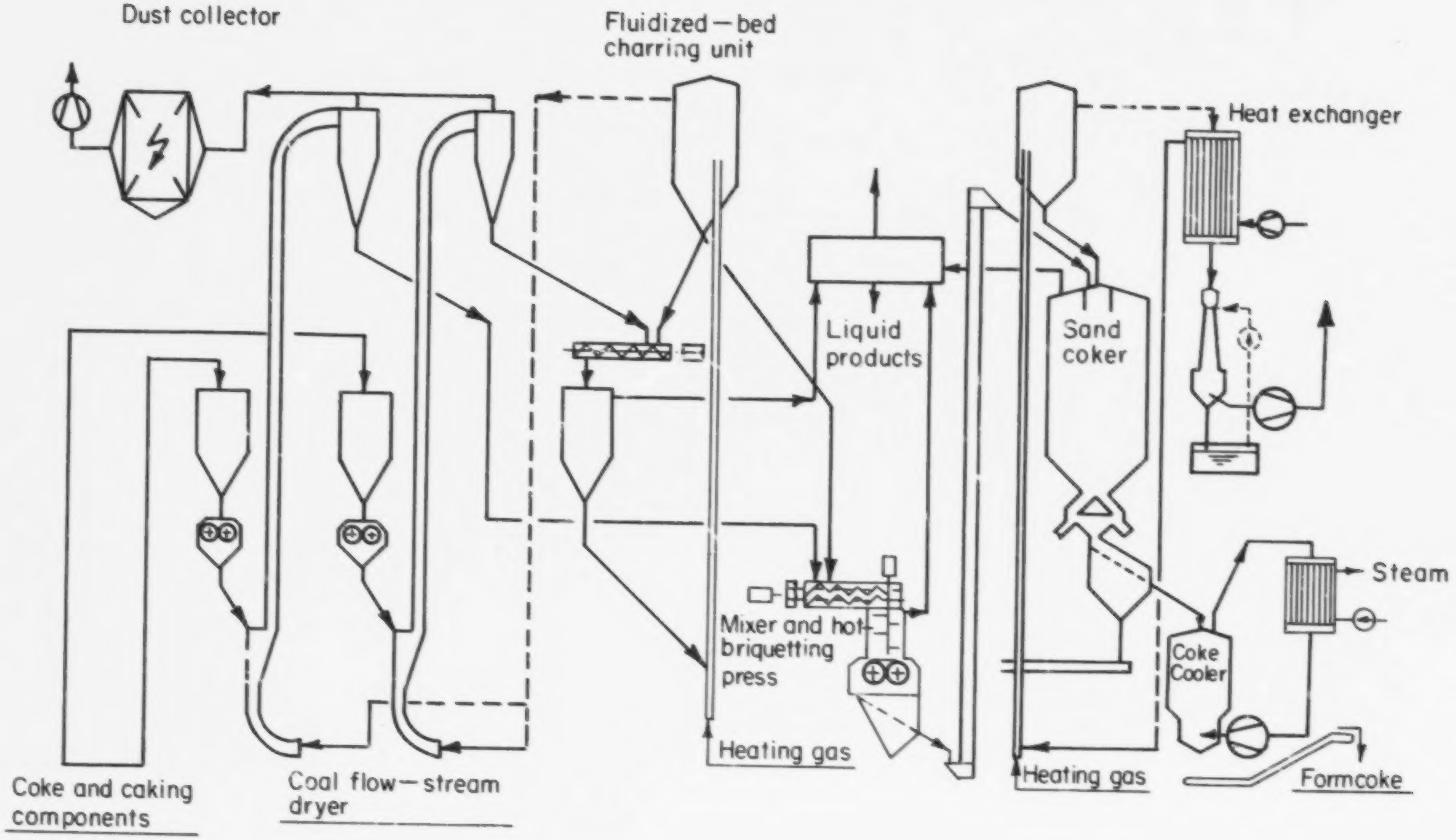

Dust collector
Fluidized—bed charring unit
Heat exchanger
Liquid products
Sand coker
Steam
Coke Cooler
Mixer and hot-briquetting press
Heating gas
Heating gas
Formcoke
Coke and caking components
Coal flow—stream dryer

FIGURE IV-5. BERGBAUFÖRSCHUNG FORMCOKE PROCESS

Fluidized Bed Charring, Hot Briquetting, (Char + Coal), and Recirculating Hot-Sand Coking

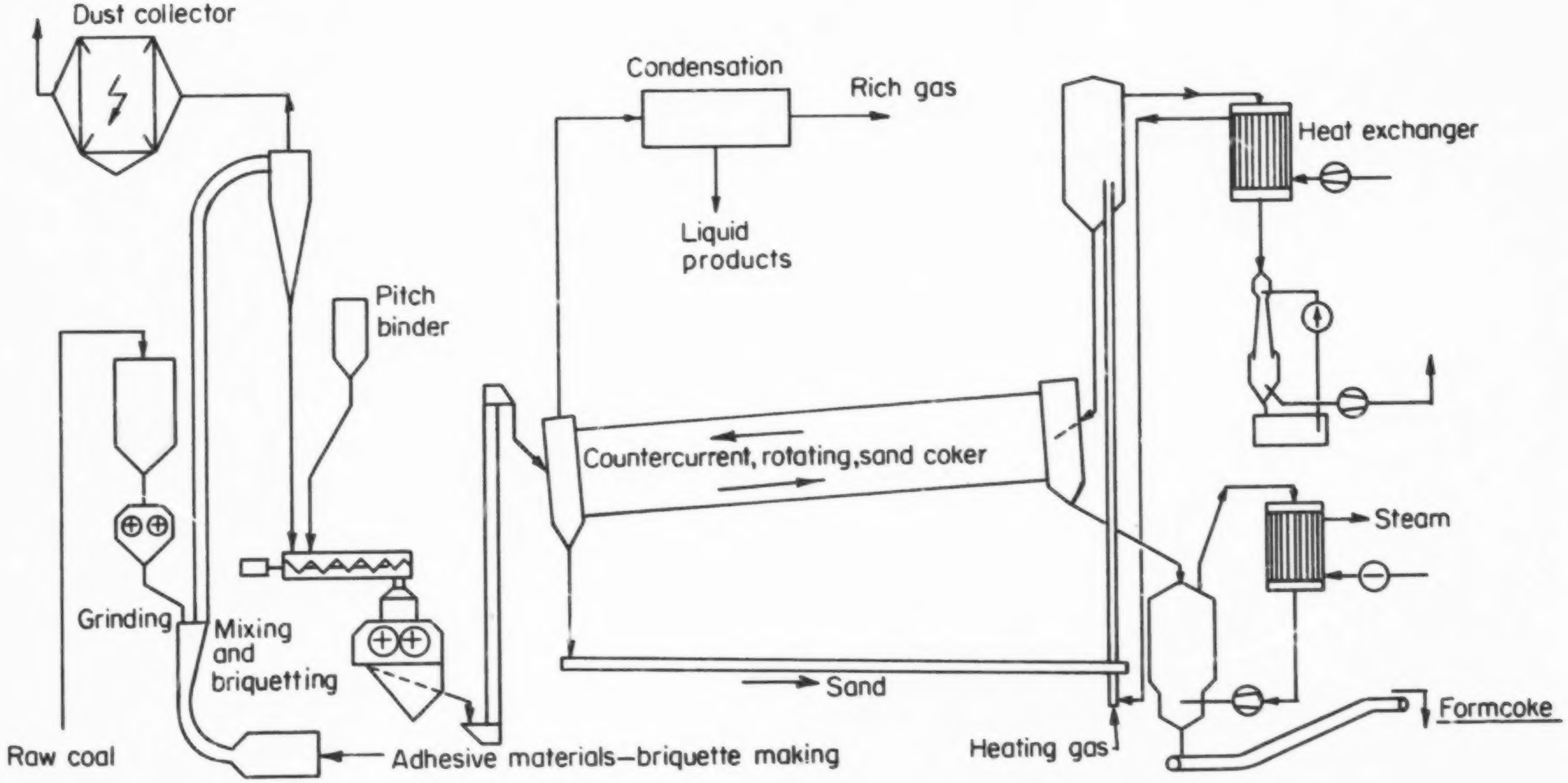
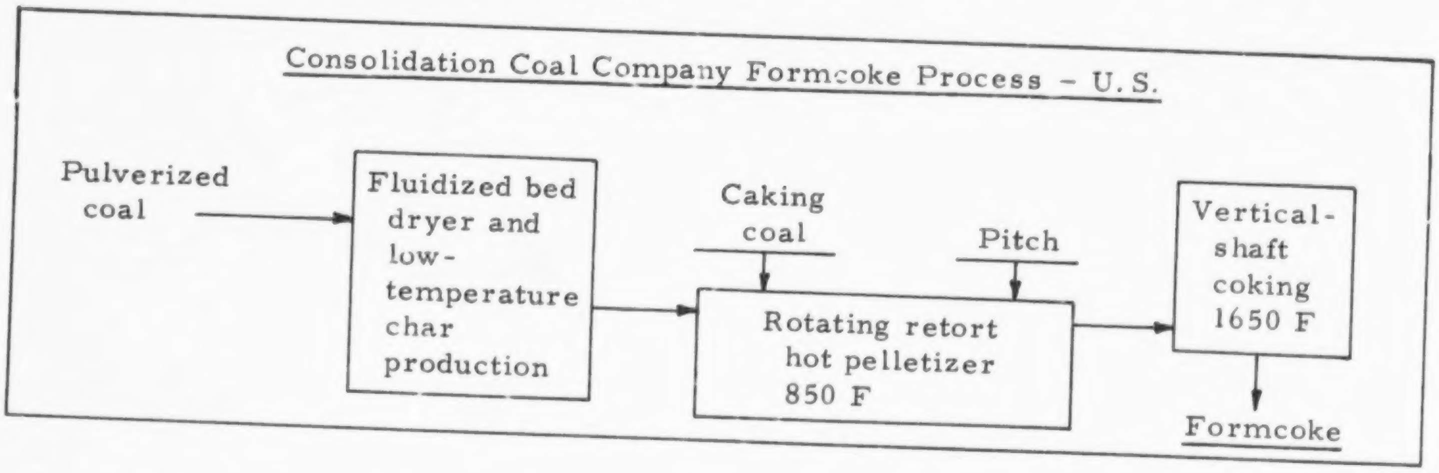

Dust collector
Condensation
Rich gas
Liquid products
Heat exchanger
Pitch binder
Countercurrent, rotating, sand coker
Steam
Grinding
Mixing and briquetting
Sand
Formcoke
Raw coal
Adhesive materials–briquette making
Heating gas

FIGURE IV-6. LURGI'S FORMCOKE PROCESS (GERMANY)

Cold Briquetteing of Coals With Pitch, Coking in a Hot-Sand, Rotating, Countercurrent Retort binding is obtained by processing the tars collected from the coal-charring operations. In a second unusual procedure, these raw briquettes are then cured to harden the briquettes prior to final coking in a gas-fired, vertical-shaft furnace. The use of calcinate instead of partly devolatilized char is intended to preclude shrinkage (and cracking) problems during final coking.


Consolidation Coal Company Formcoke Process - U.S.

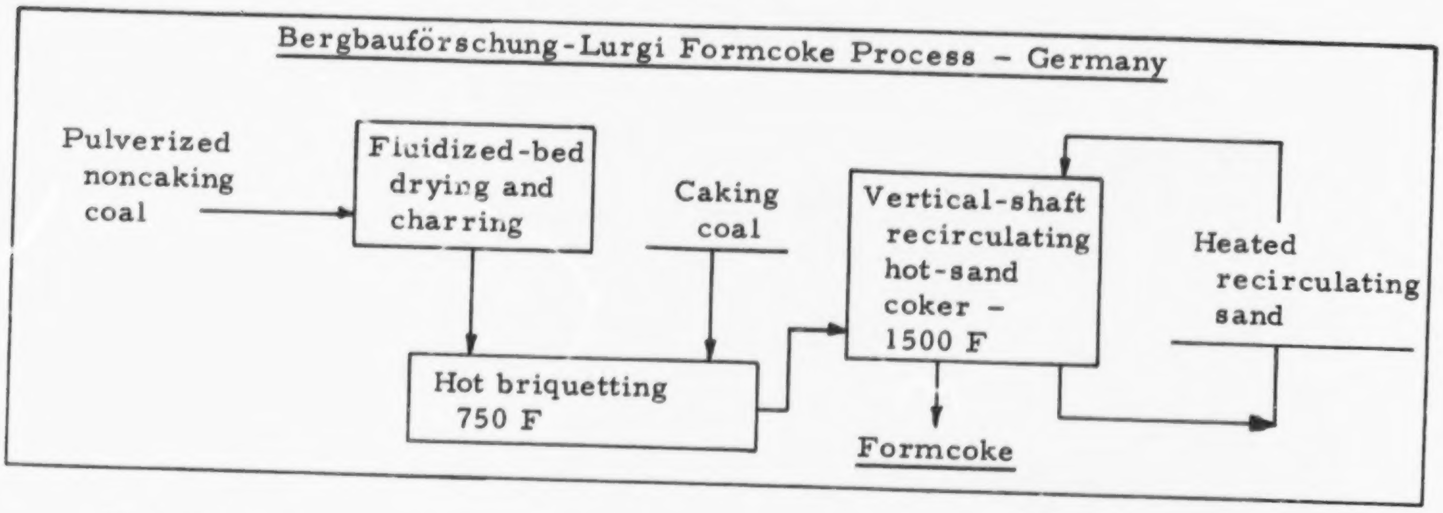
Pulverized coal
Fluidized bed dryer and low-temperature char production
Caking coal
Pitch
Rotating retort hot pelletizer 850 F
Vertical-shaft coking 1650 F
Formcoke

This process is unique in that it produces a lump directly from heated char and heated caking coal without the use of briquetting presses. In the rotating retort, the caking coal, together with char and recycle char, rolls up into balls without adherence to the sides of the retort. This unique rotating pelletizer has been successfully used starting in the 1930s, when seven retorts were used to produce up to 800 tons of smokeless fuel per day.

In the 1930s when there was a demand for smokeless fuel for homes, this was called the Disco process, and was about the only commercially successful low-temperature carbonization process in the United States. The process is not now being used commercially. At the present time, the experimental (pilot plant) retort of the Consolidation Coal Company has a capacity rating of about 1 ton per day. Plans exist to build a 30-ton-per-day unit. The process is shown in more detail in Figure IV-4.

The major feature of this process is the production of balls (sometimes called nodules) by the rolling action of heated coal in a rotating horizontal retort. This requires an input of about 50 percent caking coal. With subsequent slow coking of the raw nodules (formed lumps) in a gas-fired furnace, the formcoke lumps from this process are reported to have high strength.

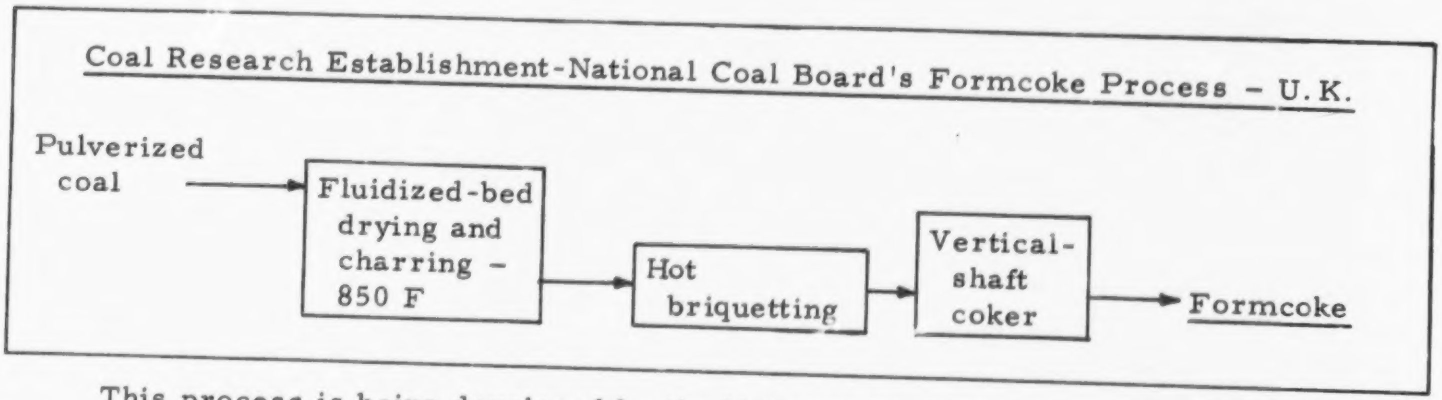
This type of formcoke was used in a 3-day trial in a small experimental blast furnace at the U. S. Bureau of Mines. The principal aim of the test was to determine the feasibility of using a formcoke as the total fuel in the blast furnace. In this context, the results were generally encouraging.


Bergbauförschung-Lurgi Formcoke Process – Germany
Pulverized noncaking coal
Fluidized-bed drying and charring
Caking coal
Hot briquetting 750 F
Vertical-shaft recirculating hot-sand coker – 1500 F
Heated recirculating sand
Formcoke

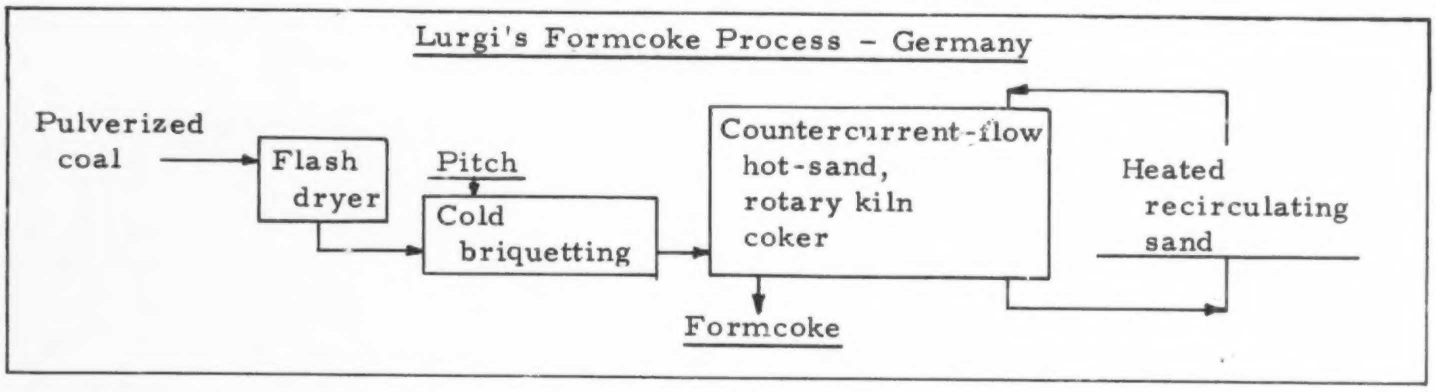
This German process incorporates most of the newer approaches used in formcoke production, including fluidized-bed charring of coal, hot briquetting, and coking using heated and recirculated sand as a heat-transfer medium. The process requires about 35 percent predried strong caking coal, and the warm raw briquettes must be able to withstand the thermal shock on entering the heated-sand coker. The process is illustrated in more detail in Figure IV-5.

Formcoke from a 100-ton-per-day pilot plant was used to fuel a large blast furnace at Hoesch in Dortmund, Germany, for a 24-hour trial. It was concluded that "formcoke showed no disadvantages as compared with the use of conventional coke".

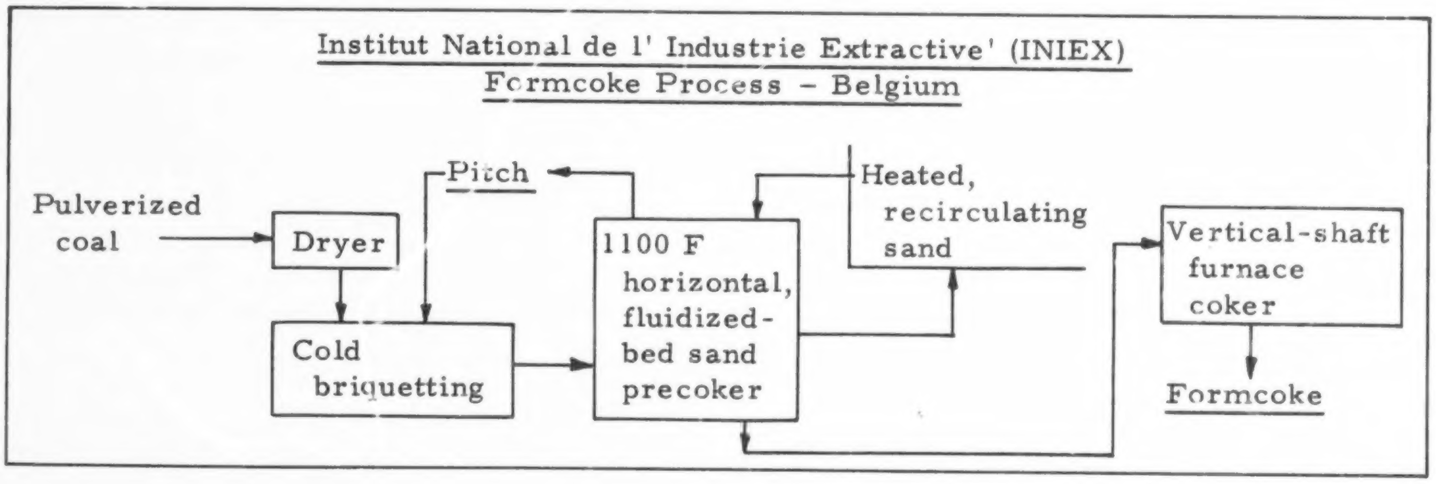
The Ruhr Coal A. G. in Germany is planning the construction of a 600-ton-per-day demonstration plant of the process (preceding sketch) for operation in the second half of 1971. This planned installation will be partly subsidized by a state government in West Germany.


Coal Research Establishment-National Coal Board's Formcoke Process – U.K.
Pulverized coal
Fluidized-bed drying and charring – 850 F
Hot briquetting
Vertical-shaft coker
Formcoke

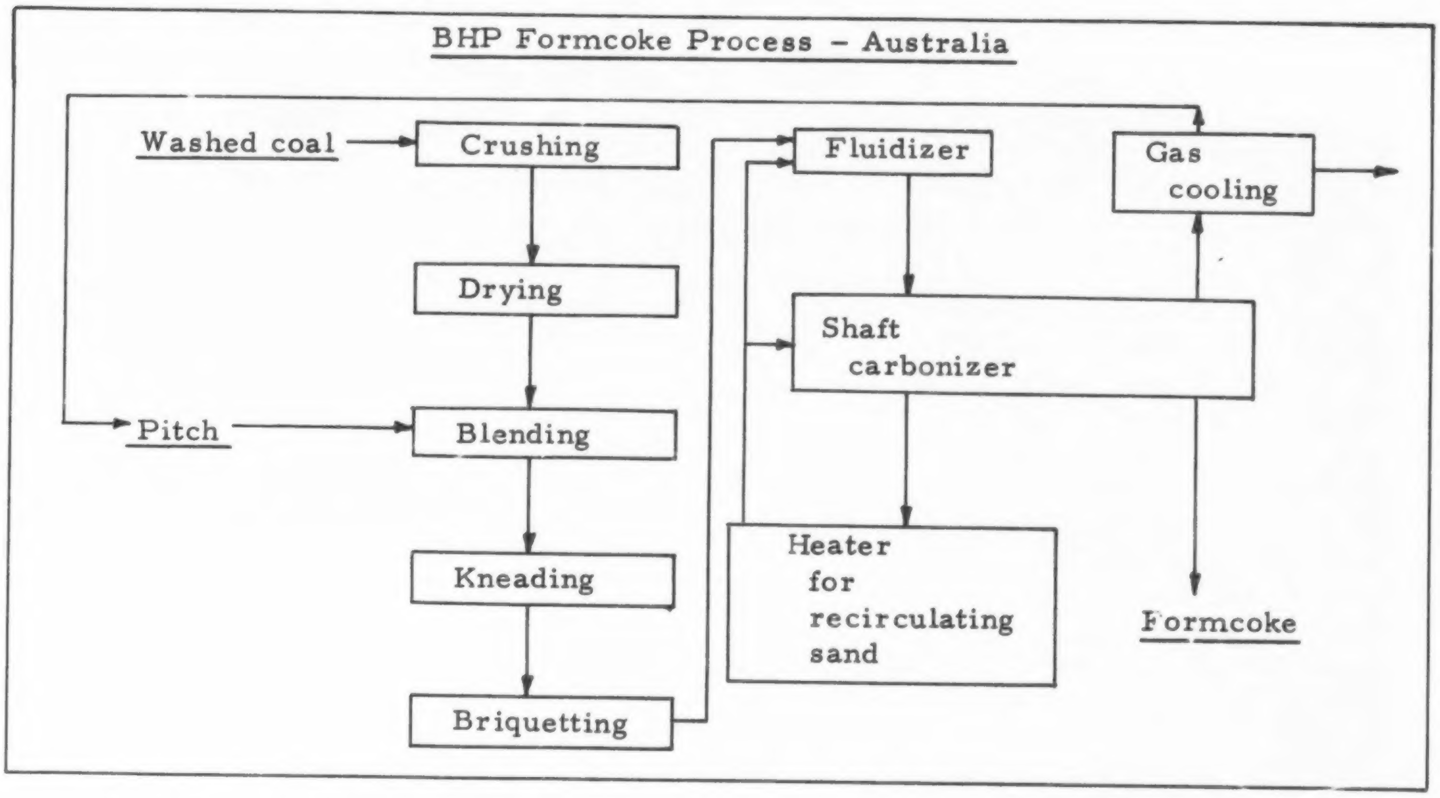
This process is being developed by the National Coal Board to use a particular high-volatile coal that is more cheaply produced in England than good-quality caking coal. The hot briquetting in this process is done without the addition of a binder, probably because of the nature of the coal being used. At the present time the pilot plant has a capacity of 250 tons per day through the hot-briquetting step. The coking step is limited to a capacity of 2 tons per day. Further development of the coking step is in progress. It has been stated that the rate of heating of the hot briquettes to 1100 F must be carefully controlled.


Lurgi's Formcoke Process - Germany
Pulverized coal
Flash dryer
Pitch
Cold briquetting
Countercurrent-flow hot-sand, rotary kiln coker
Heated recirculating sand
Formcoke

This process is in the early pilot-plant stage, with some plans for building a 10-ton-per-day unit in the near future. In an interview with Lurgi personnel, they stated that almost any coal can be used in this process, but that caking coals require a longer heating cycle or must be diluted by adding coke or char. Also, it was stated that coals with a high volatile content and with high shrinkage during coking result in a low-strength formcoke. Lurgi is of the opinion that their countercurrent-flow sand coker is more economical to operate than the vertical hot-sand coker of Bergbauförschung or the horizontal hot-sand coker of INIEX. More details of the Lurgi process are shown in Figure IV-6.


Institut National de l' Industrie Extractive' (INIEX)
Formcoke Process - Belgium
Pulverized coal
Dryer
Pitch
Cold briquetting
1100 F horizontal, fluidized-bed sand precoker
Heated, recirculating sand
Vertical-shaft furnace coker
Formcoke

This process includes an example of "shock coking" in that cold briquettes are introduced into a 1100 F fluidized-bed sand coker without preheating. The supporting and separating action of the heated sand helps to prevent sticking or deformation of the coking briquettes. At the present time, this 100-ton-per-day formcoke plant is using a low-volatile bituminous coal. It is believed that the development of this process is also being done with the aid of a government subsidy.



BHP Formcoke Process - Australia

Only a limited amount of information is available on the flow sheet of the formcoke process being developed by the Broken Hill Proprietary Co., Ltd.* Construction of a $2 million pilot plant in Australia will be started soon with the objective of making blast-furnace coke from Queensland coals which are unsuitable for use in slot ovens. BHP personnel have stated that technologically the process is undoubtedly capable of producing coke suitable for blast furnaces, and that the pilot plant is being built mainly to obtain better information on the economics of the process. It is believed that the BHP process was derived from earlier work by INIEX and will have some features in common with the INIEX formcoke process. Discussions with BHP personnel about this process revealed the interesting sidelight that control of air pollution from the coking operation was not one of the reasons for its development, and that control of air pollution from the new process has received only relatively minor attention.

Description of Continuous Coking Processes Other Than Formcoke

There are in the United States two additional types of continuous coking processes operating on a commercial scale, but which are not formcoke processes. In these, the basic coal-heating equipment is either a traveling-grate coker or a rotary-hearth furnace. Schematic diagrams of these pieces of equipment are shown in Figures IV-7 and IV-8.

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*Information given here on this process resulted from "targets of opportunity" in the form of casual visits to Battelle by members of the technical staff of BHP.

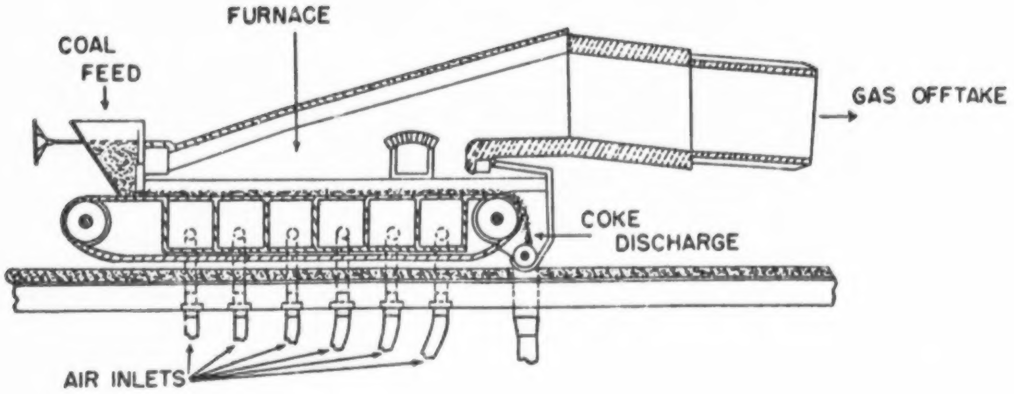


FIGURE IV-7. A TYPICAL TRAVELING-GRATE COKER

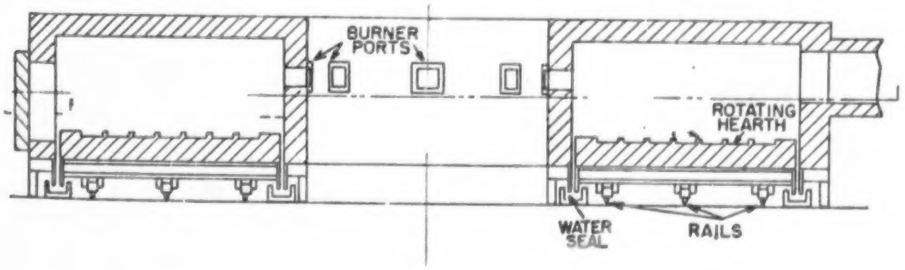


FIGURE IV-8. A CONTINUOUS ROTARY-HEARTH HEATING FURNACE

Furnaces of this configuration have been modified for commercial use as coal-coking furnaces.

At the present time, both traveling-grate cokers and rotary-hearth furnaces are being used to produce chemical coke rather than blast-furnace coke. However, in the case of the Peabody Coal Company's traveling-grate process (shown in schematic form in Figure IV-9), experimentation is in progress in an attempt to produce a stronger lump coke for possible use in blast furnaces.

Development of the traveling-grate coker is credited to the Shawinigan Chemicals Company, Ltd., Quebec, Canada. One of the innovations in the Peabody Coal Company's coking process is the addition of a refractory-lined shaft furnace following the traveling-grate coker. Partial coking is done on the traveling-grate equipment and is completed in the shaft furnace by the residual heat developed in the product during passage through the carbonizer section of the process.

Some of Peabody's experimental lump blast-furnace coke examined by the investigators appeared to have strength and sheen approaching those of blast-furnace coke. Details on the crushing strength and reactivity of the experimental blast-furnace coke are not available, and details on its production are considered proprietary.

In comparison with continuous coking by formcoke processes, the traveling-grate process appears relatively simple. However, as with all coking processes, the interrelationships of various coal characteristics and coal-heating rates are complex. No by-products are collected in this process. The major products are coke and steam.

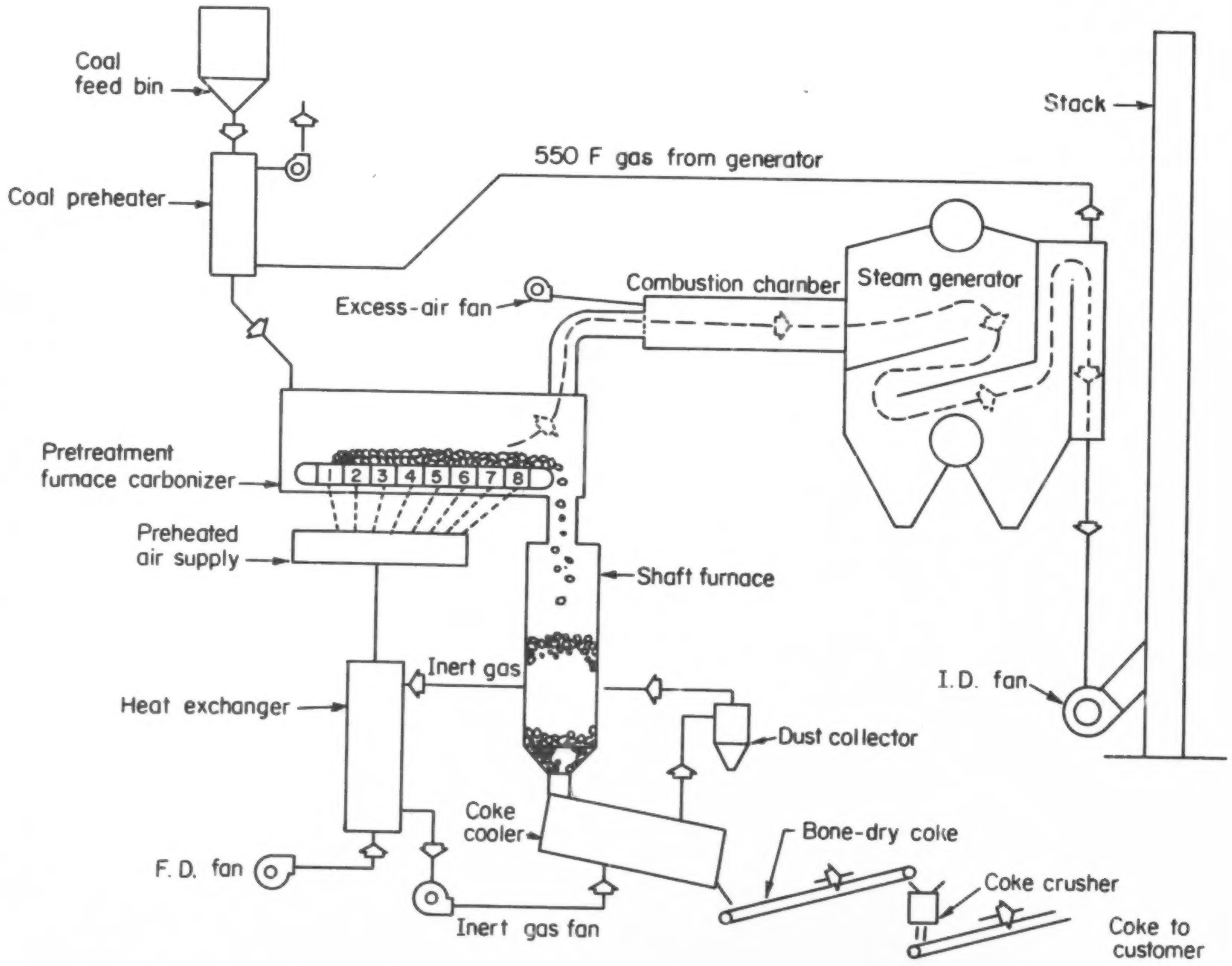

Coal feed bin
Coal preheater
550 F gas from generator
Stack
Combustion chamber
Steam generator
Excess-air fan
Pretreatment furnace carbonizer
1
2
3
4
5
6
7
8
Preheated air supply
Shaft furnace
I.D. fan
Inert gas
Heat exchanger
Dust collector
Coke cooler
Bone-dry coke
Coke crusher
F. D. fan
Inert gas fan
Coke to customer

FIGURE IV-9. PEABODY COAL COMPANY'S TRAVELING-GRATE CONTINUOUS-COKING PROCESS

No attempt is being made at this time to produce blast-furnace coke in the rotary-hearth furnace. This method is included here only because the rotary-hearth furnace has been used in the past and could be used in the future to char coal as a preliminary step in some formcoke process.

As indicated in Figure IV-8, a rotary-hearth furnace is essentially an enclosed circular furnace mounted on a turntable. In situations where these conventional continuous-heating furnaces have been modified for production of coke, coal is fed into the furnace at one point and chemical coke is removed after completion of the circular passage on the rotating hearth. The heat of carbonization is provided by the combustion of the products of carbonization over the moving layer of lump coal. Hot exhaust gases from the high-temperature zones in the furnace are directed to the zone immediately behind the feeding hopper. Air directed into the combustion zone through ports in the side of the furnace supports combustion of the gases from the coal.

Description of New Noncontinuous Coking Processes

In addition to the efforts presently under way to improve the performance of conventional slot-type, by-product-recovery coke ovens, some efforts are being made toward improvement of nonrecovery sole-flue ovens. The interest in the batch-type nonrecovery ovens is primarily because of the lower capital investment required per annual ton of coke.

The original nonrecovery coke ovens in which the volatile by-products were simply vented to the atmosphere were the beehive ovens. In those ovens, a furnace-enclosed layer of coal was heated from the top by burning some of the by-products over the coal. The modern sole-flue oven is an adaptation of the beehive oven with (1) provisions for pushing the coke product from the furnace as in conventional slot-type ovens, (2) the addition of bottom heating from flues installed in the floor (sole) of the oven, and (3) combustion of some of the by-product gas in the sole flue, with discharge of these gases into a common flue leading into the combustion zone of waste-heat boilers.

A drawing of a nonrecovery sole-flue oven constructed in 1962 in Corrimal, Australia, is shown in Figure IV-10. This type of batch oven is of only limited interest in the United States, and appears to offer no advantage over the batch-type conventional oven with regard to amenability to control of air pollution.

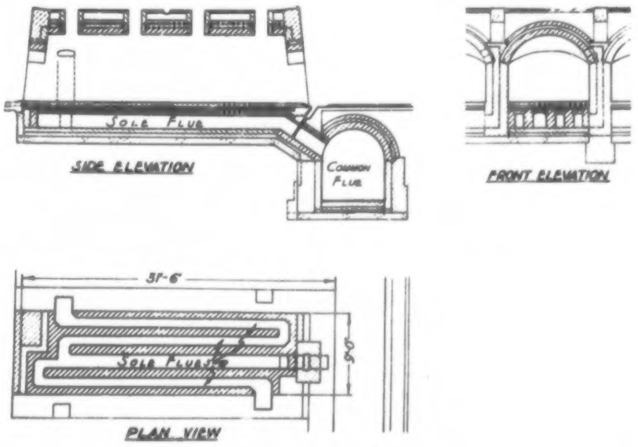


FIGURE IV-10. MODERN NONRECOVERY SOLE-FLUE OVEN CONSTRUCTED IN CORRIMAL, AUSTRALIA

Pollution-Control Potential of Specific Unit Operations in New Coking Processes

As indicated in the foregoing simplified block diagrams for various new coking processes, there are two to five unit operations involved in each process. This count includes the coke cooling and handling operations common to all processes. Ten different unit operations have been identified in this study as potential sources of emissions. These unit operations are as follows:

(1) Fluidized-bed operations for drying coal, and for oxidizing and devolatilizing coal

(2) Forming balls in a hot retort

(3) Briquetting, hot and cold

(4) Curing of briquettes

(5) Final coking in gas-fired vertical-shaft furnaces

(6) Intermediate and final coking in units that recirculate hot sand

(7) Traveling-grate cokers

(8) Rotary-hearth cokers

(9) Batch-type sole-flue ovens

(10) Coke cooling and transport.

Fluidized-Bed Operations

Fluidized-bed heaters or reactors first entered the industrial scene in 1942 with the process of catalytic cracking of crude oil, and have since moved into many other applications. In fluidized beds, a charge of fine powder or granules is kept in constant motion by forcing gas up through the mass of solids. The bed of solids in these dense-phase fluidized beds looks very much like a boiling liquid, and in some ways exhibits liquidlike behavior.

A schematic diagram of a fluidized-bed reactor is shown in Figure IV-11a, including a diagram of the internal cyclone separator used to collect and return most of the entrained powders in the exiting gas. Figure IV-11b is a schematic diagram indicating how multistage fluidized beds can be stacked one above the other rather than operating side by side.

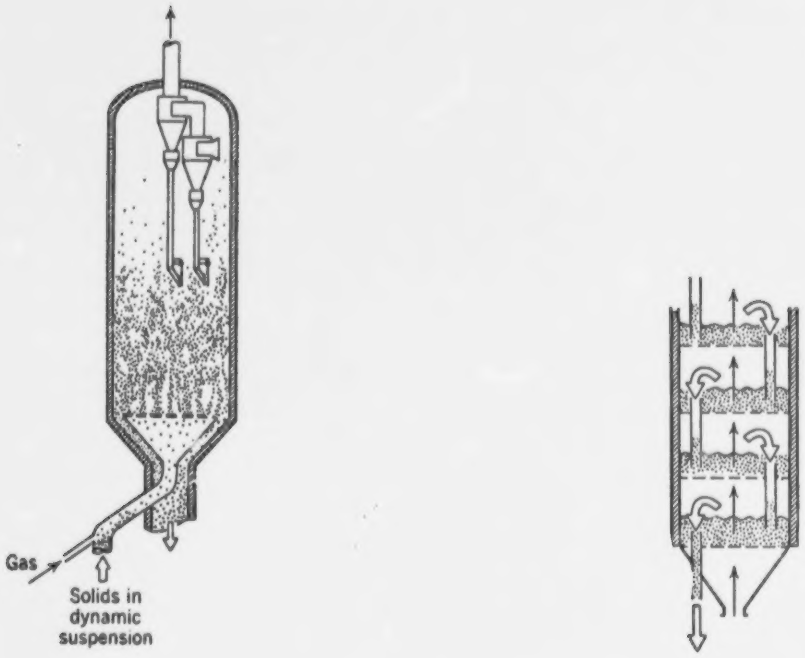


FIGURE IV-11. SINGLE AND MULTISTAGE FLUIDIZED-BED UNITS

Some of the advantages of fluidized-bed reactors in treating coals for formcoking operations are:

(1) Excellent gas-solid contact and resulting high heat-transfer rates

(2) Uniform bed temperatures and close bed-temperature controls

(3) Amenable to large-scale continuous operations, automatic controls, and transport of solids almost as if they were liquids.

These advantages continue to be of interest to formcoke producers who wish to (1) dry coal, (2) oxidize the coal to a small degree to destroy the caking and swelling properties of a particular coal, or (3) devolatilize coal either partially or completely in a series of fluidized-bed heaters each operating at a higher temperature than the first or preceding unit.

Some disadvantages of fluidized-bed units are:

(1) The residence time of solids in any one reactor is nonuniform if the reactor is operated as a continuous process.

(2) Friable solids are pulverized and entrained in the exiting gas.

(3) Attrition of even hard particles results in a very finely divided dust entrained in the off-gases. This fine dust can pass through the cyclone collectors and can become an air-pollution problem if additional control measures are not adopted.

When fluidized-bed units are used to char (partially devolatilize) coal, the coal is usually fluidized with nonreactive gas such as steam, flue gas of low oxygen content, or recycled gas. Because of dilution of the hydrocarbon gases by the fluidizing gases, the heating value of the off-gases is lowered and the volume of gas to be processed is increased. This dilution can have a bearing on the commercial value of the by-product gases.

Five or more experimental formcoke operations around the world employ fluidized beds to devolatilize all or part of the coal. The arrangement of the fluidized bed or beds and the ancillary equipment can be quite complicated, as indicated in Figure IV-12. It should be noted that, in comparison with the conventional slot-oven process, (1) the introduction of coal to the fluidized bed is a sealed operation, (2) the carbonization is done inside steel vessels, and (3) the cooling and transport of product is all done inside heat exchangers and pipes.

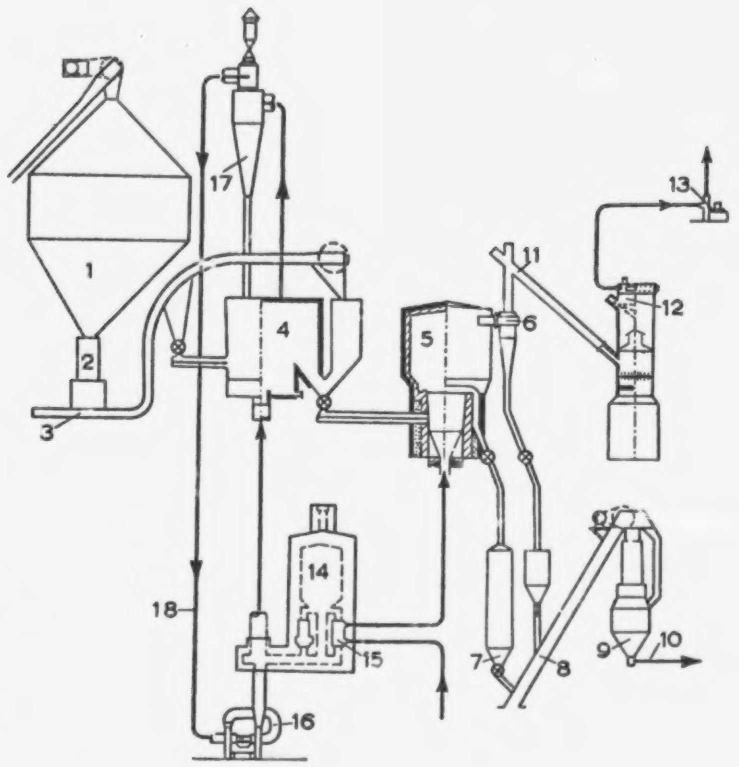
The potential air-pollution problems associated with coal carbonization in fluidized-bed units are all associated with the exiting gas streams. In fluidized beds having three or four units (usually side by side), the exiting gas from each bed has a dust content of about 9 grains per cubic foot of gas and a different composition. If all of these streams were combined into one duct, the estimated differences between this combined gas stream and the gases entering the standpipes of conventional coke ovens would be approximately as follows:

	Conventional Coke Ovens	Fluidized-Bed Charring Units
Surplus Gas Volume per Ton of Coal Processed(a), ft^3	About 6,000	Approximately 20,000 and higher
Heating Value of Gas, Btu/ft^3, gross	About 560	About 200 and lower(b)
Dust Content of Gas to Standpipe or Gas-Processing System	Low	High (by comparison)

(a) Of the total quantity of gas collected during conventional coking, about 40 percent on the average is used to fire the coke ovens. The surplus shown is gas usable for other heating.

(b) Some formcoke producers report off-gases of up to 560 Btu/ft^3, but this is off-gas from the main charring unit only, and not the heating value of the combined off-gases.

The off-gases from fluidized-bed charring units must be either (1) disposed of by direct combustion, (2) processed to remove the oils and tars and then sold in competition with clean natural gas, or (3) processed to remove the oils and tars and disposed of by combustion on the plant site. The route that is taken depends on the market or need for the oils and tars and the market for the low-Btu gas. Utilization of all off-gases directly to a boiler is expected to result in no particulate or organic pollution problem provided the temperature, capacity of the boiler firebox, and the retention time in the combustion zone are sufficient to assure complete combustion of all dust, tars, and gas. This direct-coupled combustion route is used in the Peabody Coal Company's traveling-grate coking processes and results in complete combustion. However, unless these



1. Coal bunker
2. Coal feeder
3. Feed Redler
4. Preheating furnace
5. Distillation furnace
6. Cyclones
7. Semicoke cooler
8. Bucket elevator
9. Semicoke feeder
10. Discharge of semicoke via a Redler
11. Raw-gas pipeline
12. Tar washer
13. Gas extractor
14. Combustion chamber
15. Air reheater
16. Fan for recycling flue gases
17. Cyclone in the recycling circuit
18. Pipelines for recycled gas

FIGURE IV-12. A 1-TON-PER-HOUR FLUIDIZED-BED PILOT-PLANT COAL-CHARRING UNIT AT MARIENAU EXPERIMENTAL STATION, FRANCE

gases are stripped of their H_2S content, the amount of SO_2 released into the atmosphere during combustion will be about equivalent (per ton of coal processed) to the combustion of the H_2S-bearing coke-oven gas collected during the processing of a ton of coal in conventional slot ovens. When air is used as a fluidizing gas in fluidized-bed charring units, the scrubbed by-product gas is understood to be relatively low in H_2S because the liberated sulfur ends up mostly as sulfuric acid and ammonium sulfate in the liquor stream.

When separation of tars and oils is desired, the procedure is about as indicated in Figure IV-12. From the fluidized bed (5) the off-gases pass through a hot cyclone deduster (6) and are cooled in a washer or scrubber (12). The gases delivered (13) are now expected to be clean enough for sale. Problems can arise when the lean (low-Btu) gases from some fluidized-bed reactors in a series are not mixed with the rich gases from other reactors (to avoid dilution of the rich gases). It is probable that the dust-bearing lean gases in a commercial formcoke plant can represent a disposal problem somewhat larger in magnitude than presently appreciated, but it is a problem that is definitely solvable. When nonreactive gas is used to facilitate the cooling of char, the dust content of this cooled off-gas is easily removed by bag filters.

It should be noted that oil companies have developed high-efficiency centrifugal types of dust separators to solve some air-pollution problems that were associated with fluidized-bed catalytic-cracking units. These centrifugal separators remove catalyst particles from fluidized-bed off-gases down to less than 0.04 grain per standard cubic foot.(1) It is possible that operators of fluidized-bed units in formcoke plants could use these new separators to minimize the amount of dust carryover into the tar-collection system.

Forming Balls in a Hot Retort

The Consolidation Coal Company of Pittsburgh, Pennsylvania, has a 1-ton-per-day pilot plant for balling mixtures of heated char and coal. This is probably the only experimental formcoke process not using briquetting presses. In this process, a mixture of hot char and preheated, predried caking coal (about 50 percent) is charged continuously to a rotating cylindrical retort. In the retort, the mixture forms into balls (sometimes called nodules or pellets). After discharge, the raw balls are heated in a shaft-type furnace to produce a strong formcoke.

At the present time, the off-gases from the Consolidation Coal pilot forming unit are being scrubbed and incinerated. In a commercial unit, these off-gases would be ducted to a processing section for tar removal and gas cleaning. Depending on the engineering attention and the equipment chosen to process these gases, a commercial version of this type of balling equipment is not expected to present any air-pollution problems.

Hot and Cold Briquetting

Figure IV-13 shows a working roll of a briquetting press of the type used to form the various powdered formcoke ingredients into small shapes. The amount of briquetting pressure exerted by the rolls is important because it influences the density and strength of both the raw briquettes and the final formcoke product. In general, the higher the forming pressure, the lower is the amount of fluid coal or pitch needed to cement the shapes into a strong product.

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(1) Wilson, J. G., Journal of Air Pollution Control Association, 17, 682-685 (October, 1967).

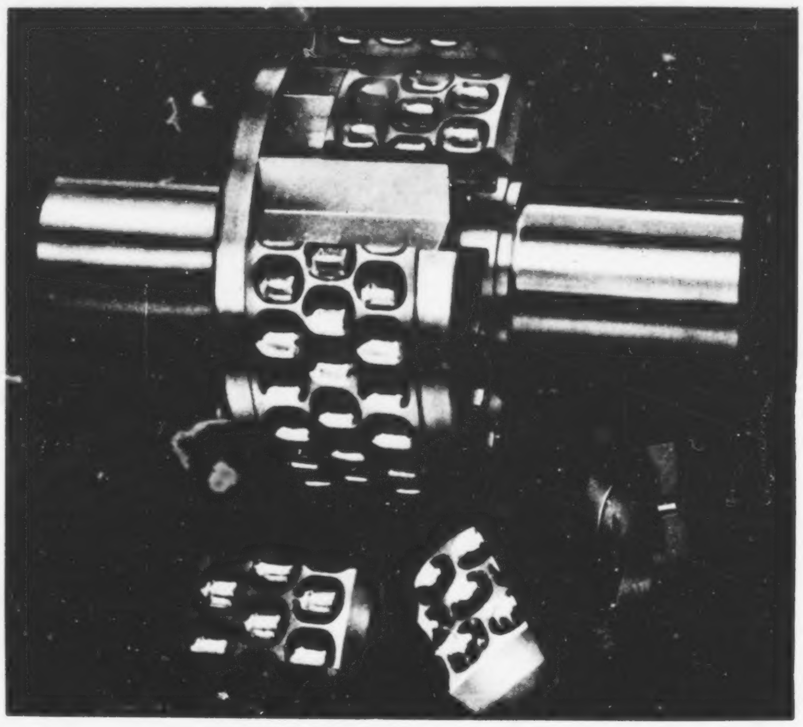


FIGURE IV-13. WORKING ROLL OF A FORMCOKE BRIQUETTING PRESS

These rolls are used in closely positioned pairs to produce the formcoke shapes shown in Figure IV-1

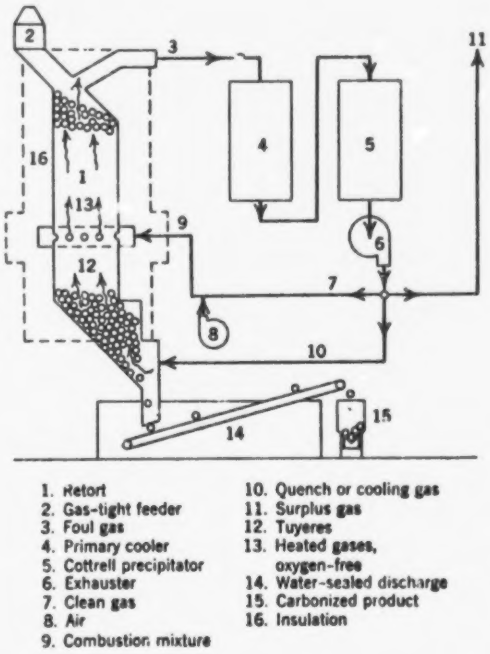
The amount and type of emissions from this operation are functions of the temperature of the pitch and coal fed to the briquetting presses. Hot briquetting is in a range of temperature where aromatic fumes are released. For hot operations, it is expected that hooding or enclosure of the rolls, with ducts leading to either the combustion zone of a boiler or to a catalytic combustion unit, will prevent pollution of the air.

Curing of Briquettes

FMC Corporation's formcoke process is somewhat special in several respects. In their multistage fluidized-bed carbonizing units, coal is almost completely devolatized to a "calcinate". The final fluidized bed in the series operates at an internal temperature of about 1500 F. Following the fluidized-bed operations, the calcinate is cooled and briquetted with pitch. These raw briquettes are then cured in a low-temperature traveling-grate oven. The purpose of this curing step is to heat the briquettes to initiate polymerization and devolatization of the pitch binder, followed by air cooling to extract the exothermic heat of reaction of the pitch and the calcinate. This secondary cooling is required to prevent combustion of the briquettes. In effect, heated air is passed through the bed of moving briquettes both to raise the briquette temperature and to maintain it within process limits. This large volume of process air becomes laden with tar and oil. and results in the release of a dense white plume. FMC personnel claim that this off-gas can be incinerated in a unit fired with off-gas from the coking kiln. However, it is probable that this smoke-laden air could represent a difficult engineering problem in incineration. The particular concern is with the large volume of polluted air produced per ton of formcoke. It may be necessary either to change this curing operation or to develop suitable incineration and procedures to attain an acceptable level of air quality from the curing operation.

Final Coking in Gas-Fired Vertical-Shaft Furnaces

Several formcoke processes use gas-fired shaft furnaces for final heating and coking of briquettes at a temperature of about 1650 F. The designs of these units vary, but generally are similar to that shown in the schematic diagram in Figure IV-14.


2
3
11
16
1
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5
13
9
6
12
7
8
10
15
14
1. Retort
2. Gas-tight feeder
3. Foul gas
4. Primary cooler
5. Cottrell precipitator
6. Exhauster
7. Clean gas
8. Air
9. Combustion mixture
10. Quench or cooling gas
11. Surplus gas
12. Tuyeres
13. Heated gases, oxygen-free
14. Water-sealed discharge
15. Carbonized product
16. Insulation

FIGURE IV-14. ONE TYPE OF GAS-FIRED VERTICAL-SHAFT FURNACE USED TO COKE FORMCOKE BRIQUETTES

The amount of heat used and the amount of gas released during the shaft-furnace operation depends on the incoming temperature of the briquettes and their volatile-matter content. The off-gases from these furnaces contain combustible gases and dust. In cases where these gases are not directly combusted, they must be cleaned. One example of the equipment required for cleaning is also shown in Figure IV-14.

A potential air-pollution problem with shaft furnaces of this type is leakage of gas and dust through the charging and discharging ports. Shaft furnaces processing a briquetted material are, in general, more difficult to seal than fluidized-bed units, and will require either (1) the maintenance of a slightly negative pressure inside the furnace to prevent the release of pollutants, or (2) ducting, incineration, and particle-collection equipment to collect and dispose of the smoke and dust.

Intermediate and Final Coking in Units That Recirculate Hot Sand

A relatively new development in the thermal processing and coking of formcoke briquettes involves various designs of hot-sand cokers. In these units, recirculating silica sand is heated by passage through a gas-fired combustion tube or furnace and is then brought into contact with the freshly made briquettes in a continuous operation. Heat is transferred from the sand to the briquettes for coking. The mass of the sand supports the briquettes and also prevents sticking and physical damage to the relatively soft briquettes during passage through the coker. In general, these recirculating-sand cokers are an improvement over gas-fired shaft cokers for low-temperature operations.

As an example of use of this technique for intermediate coking, a horizontal hot-sand coker is shown in Figure IV-15. In this case, the hot sand is used to raise room-temperature briquettes to 1100 F prior to charging the hot briquettes into a shaft carbonizer.

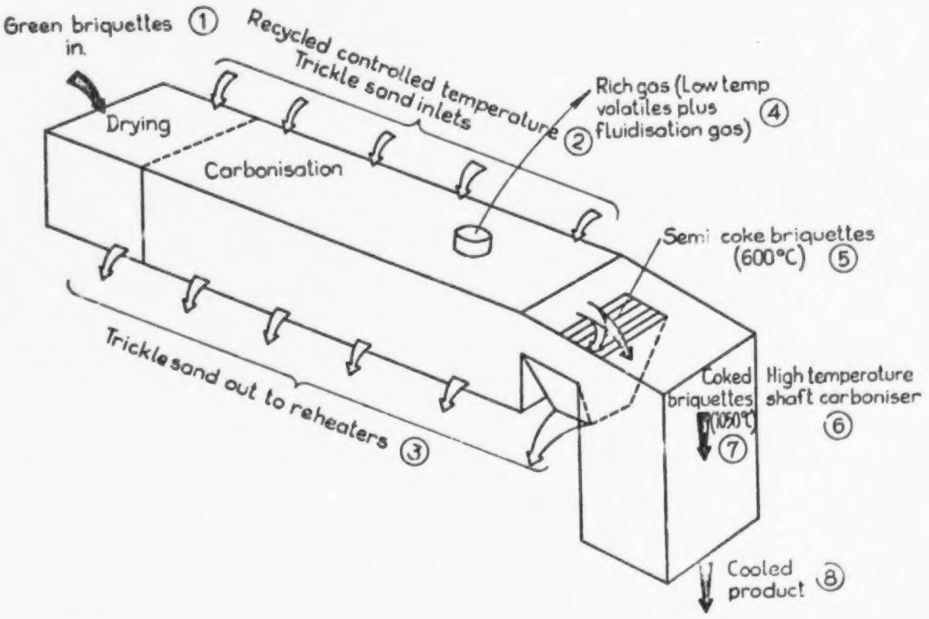
Green briquettes in. ①
Recycled controlled temperature Trickle sand inlets ②
Rich gas (Low temp volatiles plus fluidisation gas) ④
Drying
Carbonisation
Semi coke briquettes (600°C) ⑤
Trickle sand out to reheaters ③
Coked briquettes (1050°C) ⑦
High temperature shaft carboniser ⑥
Cooled product ⑧

FIGURE IV-15. ONE TYPE OF CONTINUOUS COKER BASED ON RECIRCULATION OF HOT SAND

There are several versions of hot-sand cokers in experimental use at this time. Three of the more prominent are as follows:

(1) The concurrent shaft coker of Bergbauförschung (Germany) in which raw briquettes from hot-briquetting operations are shock heated to about 1500 F by passage with hot sand down a vertical furnace.

(2) INIEX's horizontal fluidized-bed precoker which has a design similar to the diagram in Figure IV-15. It is believed that Broken Hill Proprietary's sand coker will be similar in design to the INIEX unit.

(3) Lurgi's countercurrent rotating-kiln coker. In this design the briquettes move uphill (by a mechanically induced action) against the flow of hot sand.

Coking by these methods releases both condensible and noncondensible gases which usually contain coal and coke dust. In addition, the exiting gas is diluted to some degree by the combustion products of heating.

The new pollution element introduced by sand cokers is the presence of finely divided silica sand in the exit gas. This problem precludes simple combustion disposal of the exiting gases, and introduces the requirement for stripping of condensibles and for possible processing of the cooled gas through bag filters or other suitable dust-removing equipment.

Traveling-Grate Cokers

Among the coking processes observed by the investigators is the Peabody Coal Company's traveling-grate coker shown in Figure IV-9. This type of commercial unit makes two products (1) chemical coke and (2) steam. The dust-laden gases and volatiles released during the coking step are directly ducted into the firing section of a boiler. In the boiler, combustion is essentially complete and there are no substantial particulate or organic air-pollution problems associated with this installation.

As noted in a prior description of the Peabody Coal Company's coking process, these installations are presently making chemical coke for submerged-arc furnaces. Development work is in progress in an attempt to upgrade the product to blast-furnace strength and quality. It remains to be seen whether this effort will be successful.

Rotary-Hearth Cokers

This type of furnace is a long tunnel bent into the form of a circle and enclosed in a large shell. Lump coal is fed onto the rotary table at one point, and the coke is removed after completion of the circle. Feeding, heating, discharging, and rotation are continuous. Hot exhaust gases from high-temperature zones in the furnace are directed to the zone immediately behind the feeding hopper. These hot gases raise the coal to ignition temperature. Air directed into the combustion zone through ports in the side of the furnace supports combustion of the gases released by the coal. In a 60-foot-diameter commercial rotary carbonizer operated by the Gunnquealy Coal Company in Wyoming, a 6-inch-deep active fuel bed is maintained in the furnace during a passage time of about 20 minutes. The coal and coke are agitated softly as a result of the rotation of the furnace and the action of water-cooled rabble arms.

Developers of rotary carbonizers state that the possibility that this type of furnace by itself can make blast-furnace coke is remote, but that it could make char for a form-coke process. From the viewpoint of air-pollution control, an advantage of the rotary hearth is that the off-gases are released steadily from a fixed point. Presently, the off-gases are passed through an afterburner to prevent air pollution, but they could be fed to the combustion zone of a direct-coupled boiler as is done in Peabody Coal Company's traveling-grate process.

Batch-Type Sole-Flue Ovens

Earlier in this section, the sole-flue oven for making blast-furnace coke was described as a relatively new, low-capital-cost combination of the batch-type slot oven and the older batch-type beehive oven. Further attention is given here to sole-flue ovens only for the sake of completeness and because for a period there was some interest in the United States in this Australian development. This interest has since waned, partially because of the air-pollution problems associated with this process when charging high-volatile American coals.

Coal is batch charged by conveyor belt into the top of sole-flue ovens. Thus, charging has all the emission problems associated with charging of slot-type ovens. The potential for resolving this charging-emissions problem by equipment additions and procedure modifications is, however, lower for the sole-flue ovens than for the slot-type ovens.

The underfiring of sole-flue ovens is known to cause air-pollution problems in cases where volatile coals are being coked and where there is no associated waste-heat boiler in which to accomplish complete combustion of the off-gases from the ovens.

The pushing of hot coke from sole-flue ovens can release less smoke than the pushing of coke from conventional ovens, but the emission of particulates is thought to be higher. The emissions problems arising from quenching hot coke from sole-flue ovens are about the same as those arising from quenching coke from conventional slot ovens, but the quenching of sole-flue coke is usually done without the particulate-emission control afforded by a baffled quench tower.

In general, the pollution-control potential of sole-flue ovens is poor. A few units have been built in sparsely populated areas, but it is doubted that any appreciable number will be built in the future unless it becomes practical and economical to adapt pipeline charging to this application.

Coke Cooling and Transport

During the course of this investigation it was noted that all formcokes exhibit a decided tendency to "dust" whenever a pile of product is disturbed or moved. This dusting results from attrition and abrasion of particles from the surface of briquettes. It was noted that the very finely divided dust remains suspended in still air and becomes windborne by slight drafts. Although all formcoke products actually examined during this study exhibited more dusting than did conventional blast-furnace coke*, there is a wide spread in the dusting characteristics of formcokes made by different coking processes. It appears that the higher the fluid content of the briquettes during coking, the more strongly bonded are the surface particles, and the lower is the amount of dusting during handling of the product.

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*The study did not include actual examination of cokes made by each of the processes discussed in this report.

Dusting from the product of continuous-coking processes definitely is a potential air-pollution problem, but it is a problem that can be controlled by use of equipment enclosures, suction, and air-cleaning equipment. Most chemical cokes are now transported in closed-container railroad cars. If a formcoke is particularly dusty, the coke-handling facilities at the recipient blast furnace may have to be rebuilt and upgraded to avoid a secondary air-pollution problem at this point.

Present Technical and Economic Position of New Coking Processes

Presently almost all blast-furnace coke is made in conventional slot ovens. No blast furnace is known to be using formcoke or any coke made by a continuous process. There is interest in the steel industry, however, in testing formcoke in blast furnaces. This interest is partly prompted by the expectation that the uniform size and shape of formcoke products might contribute to increased productivity of blast furnaces, somewhat similar to the way in which iron-ore pellets proved to be superior to lump ore in blast-furnace use.

Some short and generally exploratory tests of formcoke have been made in small experimental blast furnaces at the United States Steel Corporation, at the U. S. Bureau of Mines, and at AIRBO in Ougree near Luttich, Belgium. Also, short trials have been run on full-scale blast furnaces at Armco Steel Corporation (Middletown, Ohio) and at Hoesch in Dortmund, Germany. In each situation, the quantity of formcoke available for testing was limited. Partially because of this, the exploratory trials were for the most part inconclusive. A favorable factor is that the formcoke in all known instances was generally strong enough to survive the conditions in blast furnaces. There was no substantial improvement in blast-furnace productivity as a result of using formcoke. However, conditions for the use of formcoke probably were not optimum. To continue this testing program, a European formcoke producer (Bergbauförschung) is presently accumulating a supply of formcoke for a 10,000-ton trial for 1 week in a full-scale furnace sometime in January, 1970. The results of this longer trial are being awaited with considerable interest because the blast-furnace operators in this case expect to have sufficient running time to search for evidence of both increased productivity and lower consumption of coke per ton of hot metal. If there are favorable indications in this European test, longer trials will be required to obtain confirming and more extensive results. However, favorable results from the 7-day test would enhance the position of formcoke processes and accelerate the initiation of additional large-scale testing programs.

General Economics of Continuous Coking

Assuming for the moment that it eventually becomes established that the coke from a new process satisfies the technical requirements of blast furnaces, then for any such new process to challenge the slot-oven process in the United States, it is necessary for the overall cost of the new coke required to make a ton of blast-furnace hot metal to be lower than the overall cost of using conventional coke. The overall-cost concept includes the cost of coal (including delivery charges), processing or coking costs minus credits for by-products, the cost of air-pollution control, and the favorable (or negative) factor of the new coke's performance in blast furnaces.

Although final decisions by steelmakers to use or not to use formcoke on a large scale in blast furnaces will be based heavily on overall economics, a study of the relative economics of conventional coke and continuous coke is beyond the scope of this report. However, as a general guide, a qualitative summary of the cost trends in the factors making up the overall cost of conventional blast-furnace coke is shown in Table IV-1. Also included are judgmental comments regarding new continuous processes.

The economic hopes for new coking processes lie in the possible use of lower cost coal, the use of coal that now is unsuitable for use in blast furnaces, and the high value of the new coke if it improves the performance of blast furnaces. To some knowledgeable coking experts, there is now no readily apparent incentive or cost advantage for the new processes in the area of the cost of converting coal to coke. Part of this negative viewpoint is based on the fact that the new higher productivity slot-oven modifications will lower the capital and labor cost per ton of coke produced and will present a "moving target". Offsetting this, the installation of air-pollution control equipment on conventional ovens is only in its infancy, and full application of these controls can be expected to add a significant cost to each ton of coke produced in slot ovens.

Although the credit for the by-products from conventional coke ovens is in general decreasing, it still offsets a considerable amount of the conversion costs. (See Section II, page II-20.) It is important to recognize that the by-products from the new continuous processes will be smaller in amount in most instances and considerably lower in value in all instances than those realized in conventional coking. Reference was made earlier to the economic failure of many low-temperature coking processes prior to 1930. One reason for these failures was the inherent inability to realize substantial credits for the by-products. The oils and tars collected in formcoke operations are more closely identified to fuel oil than to the aromatic and thermally cracked products collected and processed at slot-oven installations. Another factor is that the by-product gases from any carbonizing process should be used to the best advantage of the coke producer by some nearby consumer. Continuous processes located away from the steel plant must, therefore, develop a customer for their gas. In some instances, the by-product gas may be a disposal problem rather than a credit.

All continuous processes studied show considerable technical ingenuity and effort, but some are handicapped somewhat by the low heating rate of coal and often by the requirement for a low heating rate to avoid melting, expansion, or cracking of the coke. These factors, combined with the low bulk density of coal and coke and the high-tonnage volume required, will result in large and expensive installations. This comes about because there has been no apparent breakthrough which has resulted in an order-of-magnitude increase in the throughput per unit volume of processing equipment. Single fluidized-bed reactors and coking furnaces can be built to a very large size to avoid the need for a multiplicity of smaller units. On the other hand, briquetting presses have an upper size limit such that a multiplicity of briquetting presses would be needed in a commercial formcoke plant.

Except in some situations where there may be a geographical advantage in coal costs in the United States, the logical early application of formcoking would be in some location in the world where there is (1) an adequate supply of noncaking coal and a shortage of caking coals, (2) a need for a coke plant somewhat smaller than a conventional coke-oven battery, and (3) a national incentive to limit the payments to other countries for caking coals. An example of such an installation is the $2,000,000 demonstration plant to be built by Broken Hill Proprietary Co. Ltd., in Australia, to produce blast-furnace formcoke from local noncaking coals.

TABLE IV-1. COMMENTS ON QUALITATIVE TRENDS OF COST FACTORS FOR CONVENTIONAL SLOT-OVEN COKING WITH RELATED COMMENTS ON NEW PROCESSES

Cost Factors for Conventional Slot-Oven Cokemaking (Algebraic Sum)	Cost Trends for Conventional Cokemaking	Related Comments Regarding New Processes
A. Cost of delivered coal	Expected to increase	Some formcoke processes can use lower cost noncaking coals.
B. Conversion cost from coal to coke		
+1. Capital cost per ton of coke	Lower with the new tall and higher productivity designs	Proponents of new processes estimate a plant construction cost (per annual ton) of 60 percent of standard-height slot ovens. Could be closer to 75 percent with taller slot-oven designs.
+2. Labor	Lower with taller oven designs	Unknown. Some estimates show a saving.
+3. Maintenance and supplies	Increasing in general, lower with new ovens with increased productivity; higher with new air-pollution control equipment	Unknown. Could be high for a new or complicated process. Most formcoke processes consume 50 kwhr or more of electrical energy per ton of coke produced.
+4. Recovery and loss factors	No apparent trend	Recovery of blast-furnace coke from coal can be slightly higher in formcoke processes where pitch binder is converted to coke. Less coke breeze is produced. Process downtime could be a problem.
+5. Overall cost of air-pollution control	Significant increase in cost expected	Part of original installation. Capital cost for controls could be higher than presently anticipated.
-6 Credit for by-products	Decreasing; decreases represent an increase in the net cost of coke	Much lower than the slot-oven credit. In some instances, the amount of credit is negligible.
+7. Delivery of coke to blast furnace	May be increasing owing to additional generation of coke breeze during sizing	Coke generally is more costly to ship than coal. Handling losses of coke are higher than for coal.
+C. Relative operating performance of coke in blast furnaces	Standard	There is hope for positive results, i.e., economic gains resulting from the use of formcoke.

Both the Australian formcoke demonstration plant and the 600-ton-per-day formcoke plant to be built by the Ruhr Coal A. G. in Dortmund, Germany, are expected to give indication of the costs for making formcoke. The coming 10,000-ton test of formcoke in a blast furnace in Germany is expected to yield technical information on the performance of formcoke. Favorable results in these foreign efforts would promote increased consideration of commercial formcoke plants in the United States.

To complete this brief evaluation of the economic position of continuous coking processes in the United States, it should be noted that efforts in other coal-processing fields could eventually result in low-cost char for a continuous coking process. In the field of chemical processing, several research projects show promise of producing quantities of char, often as a by-product. For example, the H-Coal process (developed by Hydrocarbon Research, Inc.) uses hydrogenation of coal to recover a light crude oil which can be conventionally refined to gasoline. A by-product of this process is char at about 10 percent of the original coal weight. The CSF process of the Consolidation Coal Company (and the Office of Coal Research) liquefies coal to produce a crude oil product and a char by-product. Design of a commercial plant may start in the early 1970s. FMC's COED (Char Oil Energy Development) Project is being developed to obtain maximum yields of tar and oil (plus a char by-product) from a fluidized-bed coal-charring operation. Consolidation Coal Company's CO_2 Acceptor process for coal gasification is said to have a low-sulfur char as a by-product. It is not known which, if any, of these processes produce by-product char of a quality suitable for blast-furnace formcoke, but it can be visualized that, under the proper conditions, formcoke plants could be built as an adjunct to or in combination with a large coal-gasification or coal-liquefaction plant.

SECTION V

EVALUATION AND RECOMMENDATIONS

During the course of this 6-month investigation, it repeatedly was noted that with regard to coking operations there is a meager amount of quantitative information on amounts and characteristics of emissions, performance of emissions-control equipment, or emission standards. Without adequate quantitative data, almost all discussions and interviews were of necessity couched in qualitative or semiquantitative terms. Likewise, the evaluations that result are for the most part based on judgments whose value derives mostly from the approach taken by the investigators and from the depth and scope of the investigation.

Conventional Slot-Type Ovens

1. CONVENTIONAL COKE OVENS HAVE A MULTIPLICITY OF INTRINSIC AIR-POLLUTION CONTROL PROBLEMS. OVERALL SOLUTION TO THE AIR-POLLUTION PROBLEMS OF COKE OVENS WILL BE DIFFICULT TO ACHIEVE.

Almost every observer agrees that the conventional coke-oven process for making blast-furnace coke contributes to the air-pollution problems in the areas in which ovens are located. The degree to which coke ovens contribute to local air-pollution problems is largely unknown because measurements or other quantifications of coke-oven emissions are extremely difficult to obtain and interpret. What is known positively is that many steps in the conventional processing of coal to coke have associated emissions that are at times both visible and obnoxious.

In general, the fundamental causes of the air-pollution problems associated with conventional coke ovens are (1) the large-scale batch-type operational design of these plants and (2) the nature of coal carbonization which is such that large quantities of gases and vaporized tars and oils are distilled from coal at high temperatures. The huge mass of coke required by blast furnaces (over 60 million tons per year in the United States) and the process requirement that coal be coked slowly in batches have caused construction of numerous large coke-oven installations. These plants are spread over acres of ground and have thousands of charging ports and covers, oven doors, oven vents, and seals. In any one battery of coke ovens, the leakage and other emission of gas, dust, and smoke that occurs during coking can be released from hundreds of individual, widely dispersed sources and locations.

The technical requirement that blast-furnace coke must be made at high temperature further complicates emissions control. High operating temperatures cause difficulty in sealing of doors and ports. Also, coal must be charged into the ovens without cooling them first, and this practice causes visible smoke formation.

Because of the nature of the conventional coking process, a solution to all of the emissions problems will be extremely difficult to achieve. In almost all cases, the reliable control equipment desired for the future will require considerable development effort and custom design. The special conditions and problems of controlling air pollution from coke ovens will require the cooperation of many different interests.

2. ALTHOUGH CONVENTIONAL SLOT-OVEN COKE PLANTS MAY SOMEDAY BECOME OBSOLETE, THE ESTIMATED MINIMUM TIME FOR A SUBSTANTIAL DISPLACEMENT OF SLOT OVENS BY SOME NEW PROCESS IS 15 YEARS OR MORE. IT IS, THEREFORE, IMPERATIVE TO DEAL WITH EMISSIONS FROM THE CONVENTIONAL PROCESS RATHER THAN WAITING FOR NEW TYPES OF PROCESSES TO BE DEVELOPED AND IMPLEMENTED.

In the past, when all blast-furnace coke was made in beehive ovens, the volatile by-products (about 30 percent of the weight of coal charges) were released to the atmosphere, and this practice resulted in copious air pollution. The development of the by-product coking oven to collect the valuable gas and tar by-products resulted in slow displacement of the beehive oven and, as a side benefit, gave substantial improvement in the quality of the air around coking operations.

In the context of today's need for cleaner air, the present-day by-product ovens are major sources of localized air pollution. A possible solution to this problem would be another displacement in which the present slot-oven process would be replaced rapidly by some new and economical process that can operate more cleanly.

It is the claim of some developers of new continuous coking processes that their process will avoid air pollution and can, when fully developed, replace the conventional by-product coking process for the manufacture of blast-furnace coke. If it is assumed that this contention is correct, it is nevertheless unlikely that a commercial plant utilizing such a process will be operational to make blast-furnace coke in the United States prior to 1975. If and when the first continuous coking plants are built, their operations and products will be carefully evaluated by coke users before additional major commitments are made. This evaluation may be expected to occupy an additional 5 years (to 1980). Thus, even if all results are favorable, construction of continuous coking plants replacing conventional coke ovens is not likely to begin on a general basis for 10 years after 1970. After this, it is likely that an additional 5 to 10 years will elapse before any substantial proportion of U.S. blast-furnace coke is made by a new process. These expectations lead to the conclusion that it is imperative to deal with emissions from the conventional coking process, rather than wait for new types of coking processes to be developed.

3. IT IS JUDGED THAT TOTAL ENCLOSURE OF COKE OVENS AS AN AID TO CONTAINING EMISSIONS IS NOT FEASIBLE BECAUSE THIS APPROACH INTRODUCES SPECIAL ENGINEERING, HEALTH, AND COST PROBLEMS AND DOES NOT ELIMINATE THE NEED FOR CONTROL OF EMISSIONS FROM INDIVIDUAL STEPS IN COKING.

Conventional coke ovens are large refractory structures operated in the open air. That is, there are no buildings enclosing the coking operations. Visitors to coke plants, upon observing the intermittent release of smoke and dust, sometimes have suggested that coke ovens be enclosed in buildings to improve the working conditions and to prevent the emissions from being windblown into the surrounding areas. According to this concept, the dust and harmful emissions would be stripped from the air passing through the building prior to the release of this air to the atmosphere. The concept has been considered and rejected by builders of coke ovens throughout the world.

The total enclosure of coke plants seems, at first glance, a reasonable solution, but closer study reveals that implementation would involve new problems of considerable magnitude. The open-air operation of coke ovens allows the natural dissipation of much heat and dilution of emissions. If a coke plant were enclosed, there would be need for an induced air draft of a high volume that could (1) maintain the air temperature in the building at tolerable working level, (2) dilute harmful emissions to a level where the concentration in all locations is at a level safe for humans, and (3) carry off particulate matter so there will not be a rain of grit inside the building.

From an equipment and design viewpoint, the required volume of air can be drawn through a building to make working conditions both safe and tolerable. However, the major emissions would still have to be controlled at the emissions sites. Residual emissions will thus be diluted with air to the point where they are present only in small percentages within the pollution-control and exhaust system. The technical feasibility of completely stripping small amounts of contaminants from large amounts of air moving at a relatively high velocity is low, and the cost high. If the emissions were not stripped from the exhaust air, the exhaust from the stack might appear clean but the same weight of pollutants would be leaving the plant.

It was concluded that the idea of totally enclosing coke ovens to help solve the air pollution problems associated with coking does not appear advantageous even if feasible. The enclosure approach would introduce more engineering, health, and cost problems and would not replace direct control of the individual steps in the coking process.

Practical air-pollution control engineering, as applied to coke ovens, would indicate that leaks or periodic emissions should be eliminated by process or equipment changes or modifications where possible. If an emission cannot be eliminated, it should be collected as close to the source as possible to minimize dilution. In general, these are the approaches being used presently in the development of air-pollution controls for coke ovens.

4. OF SEVEN PRIMARY SOURCES OF DUST, SMOKE, AND GAS FROM SLOT-OVEN COKING, THE MOST SERIOUS AIR-POLLUTION PROBLEM OCCURS DURING THE CHARGING OF COAL INTO THE OVENS. THE SOLUTION TO THIS COAL-CHARGING PROBLEM IS RECEIVING THE ACTIVE ATTENTION OF STEEL COMPANIES, COKE-OVEN BUILDERS, AND EQUIPMENT BUILDERS.

During the course of this investigation, several operational sources of dust, smoke, and gas from slot-oven coking were studied. The seven sources are as follows:

(1) Handling, crushing, and blending of coals

(2) Charging of coal into the slot ovens

(3) Underfiring slot ovens with fuels containing sulfur

(4) Sealing of coke ovens during the early stages of coking

(5) Discharging of newly produced coke

(6) Quenching of hot coke

(7) Handling and screening of coke.

For lack of quantitative data, it is futile to rank these operations in terms of the quantity of emissions or in terms of the probable harmfulness of these emissions. Of these seven operations, the charging of coal (Item 2), the discharging of coke (Item 5), and the quenching of hot coke (Item 6) are believed to be the most serious sources of emissions. The ratio of contribution to air pollution among these three sources is thought to be roughly in the ratio of 60:30:10.

Because charging emissions are highly visible, and because the substances released may seem quite noxious, emissions during charging have long been regarded as the major coke-oven emission problem. Although charging is the main source of emissions, fortunately it is also the object of much effort and now appears to be close to being brought under control. Presently, three systems (described in Section II) for controlling air pollution during charging of coal are under active development. These are evaluated later in this section.

5. UPON EXAMINING AND EVALUATING THE FEATURES OF COKE-PLANT EMISSIONS CONTROLS AVAILABLE (OR BECOMING AVAILABLE), IT IS JUDGED THAT THE FULLY DEVELOPED VERSIONS OF THESE CONTROLS WILL SIGNIFICANTLY LOWER POLLUTION OF AIR BY COKE OVENS. THESE CONTROLS WILL BE IMPERFECT WITH RESPECT TO COMPLETE ELIMINATION OF EMISSIONS. ALSO THE CONTROLS WILL BE COSTLY TO INSTALL AND OPERATE, AND WILL BE DIFFICULT TO MAINTAIN.

A major part of this investigative program was spent in examining and evaluating the emissions controls that are available (or will become available) for slot-oven coke plants.

In the judgment of the investigators, all of the various types of control equipment are (or likely to be) imperfect in controlling emissions, but they can contribute to significant lowering of air pollution. Probably no emissions-control equipment on any steel-company process is perfect or completely reliable in performance. The controls available or being developed for slot ovens will have to contend with considerably more difficult emissions problems than those which have been solved elsewhere.

All of the controls and concepts examined are apparently costly to install and to operate. Few of them will generate offsetting credits to the coking process. Upon examination of the engineering features and electromechanical requirements involved, it has been judged that the new emissions controls are (or will be) sensitive, and will require zealous attention to proper operation and maintenance if they are to perform reliably.

6. SOLUTION OF AIR-EMISSIONS PROBLEMS THAT ALL COKE-OVEN OPERATORS HAVE IN COMMON CAN BEST BE ACHIEVED BY GROUP ACTION AND JOINT CONTRIBUTION. ALTHOUGH IDEALISTIC, THIS APPROACH HAS BEEN STARTED AND SHOULD BE ENCOURAGED.

It is apparent that some of the delay in developing suitable control equipment for coke ovens has resulted because the normal progression of development for nonproductive equipment is different than for productive equipment. For example, if a steel company elects to be the first to purchase a new and untried piece of production equipment to realize some economic gain, the company knows that (1) the only way the builder can field-test his equipment is to sell it to some user, (2) the builder has an economic incentive to continue the development and improvement of the equipment after the sale, and (3) the steel company will have to involve its own engineering personnel to work out problems, shortcomings, and bugs. But given a joint economic incentive, the development of productive equipment continues after the sale until (usually) the user is satisfied. In the development of nonproductive air-pollution controls for coke ovens, (1) the seller often does not have a strong economic incentive to develop or improve the equipment, (2) the buyer has no economic incentive to follow up the purchase with in-house development effort, and (3) most importantly, there is often no firm standard of acceptable performance, either currently or for the future. Every coke-oven operator is aware that something must be done to improve the control of pollution from coke ovens, but the buyer-seller atmosphere is such that it can pay a steel company to "be a close second" so as to benefit from the experience and problems of others.

An answer to this part of the problem would appear to be joint participation by all coke-oven owners in the development of emissions-control equipment that can win industry and public acceptance. The American Iron and Steel Institute has recognized this and has begun large programs which presently are concerned with both equipment and procedures for control of air pollution from coke ovens.

The question of what is and what is not acceptable performance for specific emissions-control equipment and for specific coke-oven operations will continue to handicap efforts until some mix of evaluation and negotiation produces targets accepted as realistic by both coke producers and abatement agencies.

7. THE RELIABILITY OF EMISSIONS-CONTROL EQUIPMENT FOR CONVENTIONAL COKE OVENS SHOULD BE AS HIGH AS THE RELIABILITY OF THE COKING PROCESS ITSELF. ALTHOUGH ATTAINMENT OF HIGH RELIABILITY WILL BE EXPENSIVE, THE NATURE OF EMISSIONS FROM COKE PLANTS APPEARS TO WARRANT ATTEMPTS TO OBTAIN FAIL-SAFE OPERATION.

A foreseeable problem with emissions-control equipment that is proposed or becoming available for coke ovens is that some of it may require more attention and effort by the shift operator than the entire coking process would require if working without emission controls. Under these conditions, it can develop that the pollution-control equipment will not be used consistently. Because of this, the equipment should be designed such that the emissions-control function is either foolproof or interlocked with other operations of coking. Interlocking need not affect operating safety for most of the coking operations. This approach, which involves engineering of emissions controls to be a vital part of coke production, requires a high level of equipment development and reliability. The cost of developing such a reliable control will be high, and probably can be done only by support from many interests.

The investigators in this study are of the opinion that truly engineered solutions yielding reliable and consistent performance of emissions-control equipment are better than any combination of measurements, cameras, and other forms of monitoring devices.

8. IT IS RECOMMENDED STRONGLY THAT NEW RESEARCH INSTRUMENTS AND PROCEDURES BE DEVELOPED TO MEASURE EMISSIONS FROM THE COKING PROCESS. QUANTITATIVE DATA ARE REQUIRED (1) TO EVALUATE THE MAGNITUDE OF THE PROBLEMS AND TO SET PRIORITIES; (2) TO EVALUATE THE PERFORMANCE OF EMISSIONS-CONTROL EQUIPMENT ESPECIALLY DURING ITS DEVELOPMENT; AND (3) TO AID IN THE SETTING OF REALISTIC EMISSIONS TARGETS.

Engineering programs are under way in many companies to develop equipment that will control the primary sources of air-polluting emissions from conventional coke ovens. These efforts are commendable, but the programs suffer from serious handicaps because the equipment developers and users:

(1) Do not have sufficient usable data on the amounts and types of emissions they are supposed to control

(2) Do not have adequate sampling techniques and analytical methods to measure the performance of the equipment they are trying to develop.

This situation exists because:

(1) The development of equipment and techniques for representative sampling and quantitative measurement of the emissions from coke ovens is inordinately difficult.

(2) The difficulties are such that the techniques that are developed are open to criticism and can have limited acceptability.

(3) There are many individual developers of equipment and hundreds of potential users, few of which individually have both the inclination and resources to support and conduct research to develop measurement techniques that may never become generally acceptable.

Because many steps in the conventional coking process are batch operations, some of the major emissions occur mostly during short, recurrent intervals of time; and during the short intervals, the emission rate and emission composition are changing. To obtain quantitative data, it is apparent that specialized test equipment and techniques must be developed. These specialized techniques are needed first for research purposes.

For example, scrubbers on larry cars are being sold at the present time with no quantitative specifications as to the degree of control or of expected performance with respect to aromatic vapors. If accepted sampling and analytical procedures for the scrubber-discharge gases were available, the variables that affect the degree of control of these combined collection, combustion, and scrubbing units could be studied at one new installation. The information obtained would guide the nature of improvements to be incorporated into the models offered subsequently for sale.

It is judged that direct quantitative measurement techniques of a research nature could be developed for most of the sources of emission from coke ovens. However, it may in some instances be more practical to use semiquantitative techniques. For example, in a research study to determine the effect of coke-oven operating variables on the amount of smoke released during the discharging of hot coke, it is expected that a photographic technique might be appropriate to present and substantiate the research results. Laboratory tests might, however, be developed to relate the quantity of smoke released from a small quantity of coke to (for example) the final volatile-matter content of the coke.

Measurements and standards are always a problem for any industry, but operation without guidelines or agreements on emissions targets can be confusing and disruptive. It is considered more important at this time that research be done to develop improved research measurement techniques than that these techniques be flaw-free and accepted by everyone. Agreement on targets and on measurement techniques is seldom unamimous, but the degree of acceptance can be highest when the program of research is supported by all of the interests involved.

It is a principal recommendation of this study that research instruments and procedures be developed to measure the various emissions from the slot-oven coking process. There is no way at the present time, for example, to determine quantitatively (1) whether leakage of coke-oven door seals is a more serious problem than the very different emissions from quenching of hot coke in uncontrolled quenching towers or (2) how either of these two emissions rank in quantity or possible harmfulness by comparison with other industrial emissions.

9. IT IS RECOMMENDED STRONGLY THAT EACH OF THE THREE ACTIVE (AND ATTRACTIVE) SYSTEMS FOR CONTROLLING EMISSIONS ASSOCIATED WITH COAL CHARGING TO SLOT OVENS BE MORE FULLY DEVELOPED. THE DEVELOPMENT OF EMISSION-MEASUREMENT TECHNIQUES THEN WOULD MAKE IT POSSIBLE TO CHOOSE RATIONALLY AMONG THESE COMPETING SYSTEMS.

Recent years have seen the beginning of active development programs directed toward alleviation of emissions associated with the charging of coal into slot ovens. Active development in the present context means that substantial amounts of money have been spent and are being spent on engineering and equipment. The solution being sought is complete or almost complete control, not just partial alleviation of the problem.

There are three active and highly attractive types of systems in competition for industry acceptance as practical means to control charging emissions. These systems are as follows:

Type of System	Some Company and Organization Names Associated With These Systems	System Status and Comments
Direct collection and wet scrubbing of charging smoke	Koppers Companies (U. S. and Germany) Hartung and Kuhn (Germany) Schalker-Fisenhütte	Available for sale and installation. Continuing development required. Operation of by-product system is not affected.
Charging on the main from larry cars with closed coal ports	American Iron and Steel Institute (U. S.) Firma Carl Still (Germany)	In active development. The AISI system is designed to accommodate the high-volatile American coals and will include system automation. One or more years of continued development is required.
Sealed pipeline charging	Allied Chemical Corporation (U. S.) Tailor & Company (U. S.)	Allied Chemical Corporation's system is in active development. System is designed primarily to speed coking, and not to eliminate air pollution. However, the elimination of top charging ports will eliminate this source of emissions. There could be pollution emissions problems from the by-product system. Two or more years required to demonstrate the technical and economic feasibility of the approach.

It should be noted that there are two approaches represented in the above three types of systems. One approach (represented by scrubbers on larry cars) is to collect the emissions as they come out of the charging ports, and then to process them by combustion and disposal. The other approach (represented by the other two systems) is to eliminate the charging ports as sources of emissions, i.e., to exhaust via the by-product-recovery system. The Allied Chemical Corporation system completely eliminates the charging ports in favor of a closed pipeline; and the AISI and Firma Carl Still systems keep the charging ports sealed to the larry car while exhausting to the by-product system. The control of emissions by elimination of the known sites of emissions (e.g., the charging ports) has appeal. However, questions remain as to (1) whether or not this can be done practically, and (2) what secondary air-pollution problems (if any) may be generated in each system. This information can be determined only in full-scale tests.

An ideal solution to an air-pollution problem can occur when an equipment or procedure modification alleviates the emissions and is at the same time economically favorable to the operators of the process. Such ideal solutions are rare. However, the possibility of such solutions must be exhaustively studied because they would lend clear economic incentives for the development and installation of the modification. In this regard, some economic information on the three systems of interest is as follows:

Type of System	Ratio of Estimated Installed Cost per Coke-Oven Battery[(a)]	Judged Possible Economic Incentive to Owner	Expected Acceptability to the Steel Industry if Approach is Successful
Direct exhausting to scrubbers on larry cars	1	None	Moderate, although partly successful now
Charging from larry cars with closed coal ports	2 to 3	May be some incentive with automation that lowers need for manpower	High for the AISI system. Automation is a requirement for control of air pollution.
Pipeline charging	3 to 5	High if productivity of the ovens is raised	High for some plants. Whether and when a coke plant will buy this system will be influenced by the plant's need for more coking capacity.

(a) These capital-cost relationships are Battelle's estimates based on evaluation of speculative estimates obtained from various sources.

Pipeline charging has the potential of being an ideal solution for a new coke plant or for an existing coke plant that needs added capacity. Because of the expected high incentive that may exist for the purchase of the pipeline charging system (if successful), the emissionscontrols associated with this system should be developed to the degree where they will meet anticipated future targets for control.

It has not yet been determined whether there is any economic incentive associated with the AISI system, but there may be one if the system is completely automated so as to lower the manpower used on conventional ovens.

There is no economic incentive to install wet scrubbers on larry cars, except that this system may have the lowest first cost.

All three of the systems under discussion are more or less in the development stage, although the larry-car-scrubber system is more advanced timewise in that scrubbers are being sold now to U. S. coke plants. The other two systems have reached a stage of development where demonstration and prototype units are definitely being planned. Because these closed-port systems are in development, the specific operational aspects are not known as yet. Because details and some information are considered proprietary, no specific judgment is warranted at this time as to their relative effectiveness, reliability, operating practicality, industry acceptance, and cost. However, all three systems have the potential to satisfy these criteria.

The AISI system appears to be aimed specifically at control of emissions from charging, including the development of automation that will bring into balance and coordinate all of the various activities required for the system to fulfill its function. This system has potential for development to the degree where control of air pollution during charging can have the same reliability as production of coke. The design can include engineered interlocks so that the charging process could not operate if critical parts of the air-pollution controls were ineffective for some reason. As a simple example, if the drafting performance of the steam jet in any ascension pipe is below standard, emissions will probably be released from the charging ports of that oven. It should be possible to monitor the suction performance of each steam jet prior to starting the charging sequence. It should be appreciated that considerable field testing and field development are required before any highly mechanized system will reach a high level of reliability.

It appears probable that with both the pipeline charging system and the AISI-type system special provisions will have to made for avoiding the carryover of coal dust into the by-products systems. If the carryover of coal is excessive, it will increase the frequency of cleanouts of the piping and equipment that lead to and are part of the by-product recovery system, especially the primary coolers and the tar decanters. This could result in an undesirable increase in emissions to the air from these sources during cleanout. Consideration of this possibility should be part of the overall evaluation of the pollution-control performance of the closed-port systems.

As all three types of systems for controlling emissions during charging become further developed, it is predictable that the question will arise as to what is acceptable performance. This question should be answered at this time before designs become fixed and before extensive installations are made. In Germany, the VDI* standard for larry car scrubbers is that they shall remove at least 96 percent of the particulate matter. There is little information on how and on what basis compliance is determined but it does give the designers a target. Admittedly, target-setting is a complex problem with complicated ramifications. For example, suppose the 96 percent target for larry-car scrubbers were also adopted in the United States. An important question could be "How many grams or cubic feet of miscellaneous emissions from the Allied or AISI closed-port charging systems are equivalent to 4 percent emissions from a larry-car scrubber?" Acceptable procedures should be developed for sampling and analyzing emissions to obtain quantitative research and equipment-performance data.

Considering the above information and discussions, it is Battelle's judgment that none of the three active types of systems for controlling charging emissions stand proved or disproved for use in the United States. The fact that there are three potentially useful types of systems in competition for industry acceptance is highly encouraging. It is recommended, therefore, that each of these types of systems be diligently developed and demonstrated to the point where, given measurement techniques and emissions targets, it will be possible to choose rationally among them. Because air pollution from charging smoke is regarded as one of the most serious problems in coke-oven emissions control, encouragement should be given to facilitate application and in-service evaluation of these methods with high potential to lower the emission of such smoke.

In addition to the consideration of capital and operating costs, widespread implementation of any system for controlling charging emissions will be influenced by the intangibles of know-how, immediacy, and acceptance by the steel industry. On balance, Battelle sees a considerable practical advantage to encouragement and support of the AISI plan to install commercial-scale equipment to demonstrate the capabilities of a system resulting from recent and current AISI research.

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*Verein Deutscher Ingenieure = Association of German Engineers.

Battelle expects that means for collecting emissions during charging of coke ovens can be installed on a few batteries (perhaps three to six) by 1975. Whether or not such systems will accomplish the desired results is still to be determined. The problem has difficult technical aspects, but it can be solved. Industry acceptance of any particular system will depend upon individual company analysis of the facts as they develop and as they relate to the particular company. It could develop that one system will become dominant, or that different systems will be used in different circumstances. For example, the choice of a larry-car scrubber system may be the result of a decision that a particular coke-oven battery has only a limited life. Also, the final choice may be affected by the end use of the by-product tar. Whereas insoluble solid materials (such as result from coal carryover) are undesirable in tars to be processed chemically or to be used as liquid fuels, they are desirable in some tars used for paving.

10. IT IS RECOMMENDED THAT A RESEARCH PROGRAM BE CONDUCTED TO DEVELOP A BETTER UNDERSTANDING OF THE TECHNICAL VARIABLES THAT CONTRIBUTE TO SMOKING OF NEWLY PUSHED COKE. THE RESULTS COULD BE HELPFUL IN ALLEVIATING THIS SMOKE PROBLEM. ALLEVIATION WILL EASE THE PROBLEMS OF DEVELOPING EFFECTIVE EMISSIONS-CONTROL EQUIPMENT.

The emissions released from hot coke during the discharging (pushing) of individual ovens is probably the second biggest source of air pollution from slot-oven coking operations. (Emissions during charging of coal are the major source.)

This problem has a variable complexity because there can be two types of pollution involved: (1) dust from thermal drafting of coke particles and (2) smoke from some fraction of incompletely coked coal (green coke).

The dust-release problem is common to all coke-oven discharging operations, and is mainly a highly localized (in-plant) problem. In instances where the dust released from thoroughly coked coal is carried outside of the plant limits, it is judged that a relatively small mobile hood arrangement that exhausts through wet scrubbers will effectively alleviate the problem. Such a pushing-emissions control machine is sold, for example, by Hartung and Kuhn (Germany). However, this equipment cannot capture the large amounts of dust and smoke that are released when green coke is pushed.

The actual discharging or pushing of an individual oven is accomplished in a short period of about 1 minute. During this period, the 10 to 16-ton cake of hot coke is exposed to air as the cake crumbles into lumps and is spread out over the length of the quenching car. With a push of low-volatile-content coke (little or no green coke), a strong draft of heated air (with some dust and combustion products) rises into the atmosphere. With a green push, there is rapid combustion of hycrocarbons in addition to the normal thermal drafting. This rapid exposure and combustion of hydrocarbons results in an increase in the volume (and temperature) of the plume and an increased generation of smoke. The problem increases in magnitude with increased amounts of hydrocarbons in the pushed coke. In an extreme case, a green push can result in a large smoky flame reaching a hundred feet into the air.

Discussions with European and American equipment designers about proposed emissions-control equipment on the pushing side of the ovens show that little or no thought is being given to the problem of handling the smoke from a green push of coke. This situation exists because capture of emissions during the pushing of green coke will be extremely difficult. Battelle concludes that (1) the control of smoke released during pushing will be costly and difficult to accomplish once the smoke is generated, (2) coke-oven operators should take immediate steps to minimize the frequency of green pushes resulting from conscious decisions to push early, and (3) research should be conducted to develop better understanding of operating practices that might be used to inhibit the air-polluting effect of early pushing.

Evaluation of the smoke-control problem during pushing is aggravated by the fact that there is a wide range in the quantity of smoke released at different coke plants. The problem is definitely minor at some plants and major at other plants, and can vary from time to time at any one given plant, depending on the conditions of coking. Also, the amount of smoke released depends partly on operational decisions and partly on technical dificulties.

The smoke that is released as a result of operational decisions is often (but not always) caused by deliberate shortening of the coking time in some ovens (1) to increase the production rate during some periods of high demand for coke or (2) to get back on schedule after a breakdown or some other interruption of the schedule. In these situations, the release of significant amounts of smoke is a result of a conscious decision. Other decisions (such as deliberate overfilling of the ovens) can also cause green coke. It can, however, be expected that the quantity of smoke caused by these operational decisions will be reduced as pollution control receives a high priority for attention by coke-plant operating personnel. Further improvement in control of smoke will then depend on resolution of some of the technical problems.

Coke-oven builders in both the United States and Europe have widely differing opinions as to whether green coke resulting from technical conditions (such as residual green coke against the cold doors of the ovens) can ever be eliminated. Some designers (and some operators) take the position that all of the problems have been identified and can be resolved, while others take the position that certain oven designs have individual problems requiring both research and modification of the ovens. As a result of this evaluation, it is concluded that the problem is more complicated than it would first appear, and that a plant-oriented research program should be conducted on the relationships between green coke and these variables of practice:

Coal volatile matter
Coal bulk density
Original coal moisture
Oven-fill level (as related to flue design)
Coking time
Rate of heating
Temperature gradients.

From research of this type, it should become possible to obtain improved control of pushing smoke. Because of differences in conditions from plant to plant, this research, some of which must be experimental, should be done in (or in cooperation with) at least three coke plants.

It is presumed that developments in the three European systems (described in Section III) aimed at collecting low-smoke-content emissions from discharging will be observed closely by individual steel companies and by the Manufacturing Problems Committee of The American Iron and Steel Institute. The coming trials of these systems should lead to clear criteria for a new American pushing system or a combined pushing and quenching system. It is considered possible that knowledgeable steel-company personnel could devise a coke-side apparatus that would have sone potential cost benefits. An efficient approach would be for all potential purchasers of such an apparatus to share in the cost of its development. Until such time as some collection system gains industry acceptance, positive steps to minimize the smoke released during pushing depend mainly upon the efforts of steel companies to minimize the amount of green coke that is pushed.

11. IT IS RECOMMENDED THAT A VERSION OF A GERMAN BACK-PRESSURIZATION SYSTEM THAT IS DESIGNED TO ALLEVIATE LEAKAGE OF TARRY SMOKE FROM SLOT-OVEN DOORS BE INSTALLED ON A COKE-OVEN BATTERY IN THE UNITED STATES ON A DEMONSTRATION-DEVELOPMENT BASIS.

In all but exceptional coke plants, coke-oven doors typically leak tarry smoke for up to an hour at the beginning of the coking cycle. This leakage continues until tar deposits effectively close gaps in the metal-to-metal seals. Because there is no information available on the volume of smoke that leaks from doors at various plants, it is impractical to gauge the overall magnitude of this air-pollution problem. On the basis of appearances and the knowledge that there are thousands of coke-oven doors, this source of emissions is a serious problem.

From discussions with coke-oven builders and operators, it is judged (1) that the new taller ovens are more difficult to seal than ovens of conventional height, (2) that the seal-cleaning and jamb-cleaning machines that are being developed may help minimize the leakage problem but will not eliminate it, and (3) that successful solution of this problem requires some new approach that does not depend on the degree of diligence of shift operators and maintenance personnel.

At the Zollverein Works of the Rhein-Elbe Coal Company in Germany, during the course of this study, the investigators were shown a back-pressurization system. This system shows promise of being a successful new approach and perhaps a solution to door-seal maintenance difficulties. Coke-oven gas injected through the doors pressurizes the seal area and prevents migration of tarry smoke and vapors to the jambs and seals. Most of the back-injected gas is merely recycled into the by-product system, but a small fraction breaks down to give a deposit of fluffy carbon powder on the seals. This deposition results in a tight seal early in the cycle. In England, Simon-Carves has adapted the Zollverein principle and has used it with the coke-oven gas ducted through the door frames, rather than through the doors. This change eliminates the need to make and break connections to the back-pressure system. It is claimed that the door seals are easier to clean and that the maintenance of doors is greatly eased.

It is judged that this system is far from being a cure-all, and that there are some limitations both in the system and in its application, but it is a tested, new, and practical-sounding idea for stopping or alleviating door leakage. Costs and benefits will be known more definitely after the British installations have been in service for some months.

12. IT IS RECOMMENDED THAT THE GAINS MADE POSSIBLE IN CONTROL OF EMISSIONS FROM COKE QUENCHING BY (1) INSTALLING BAFFLES OR RESTRICTIVE DEVICES IN QUENCH TOWERS AND (2) ELIMINATING THE USE OF CONTAMINATED QUENCH WATER SHOULD BE APPLIED MORE EXTENSIVELY TO QUENCHING OPERATIONS IN THE UNITED STATES.

In the interest of improving air-pollution control at steel plants and improving working conditions around steel-company processes, many companies (1) have installed emissions-control baffles and devices inside of quench towers to prevent the release of about 90 percent of the grit and dust formerly emitted to the atmosphere fron uncontrolled towers and (2) have discontinued the practice of using contaminated water for the quenching of hot coke. When used, these modifications in procedure and equipment have almost eliminated emissions from the quenching operation as a major source of air pollution.

13. IT IS RECOMMENDED THAT THE RESEARCH IN PROGRESS TO DEVELOP AN EFFECTIVE AND LOW-COST METHOD OF STRIPPING HYDROGEN SULFIDE FROM COKE-OVEN GAS BE INTENSIFIED.

According to the National Air Pollution Control Administration's Publication No. AP-52, "Control Techniques for Sulfur Oxide Air Pollutants" (January, 1969), the slot-oven process releases about 500,000 tons of SO_2 pollutant per year when coke-oven gas and tar are used for combustion heating. On the basis of estimates of the total amount of SO_2 released to the atmosphere from all sources, the combustion of coke-oven gas contributes a maximum of about 1.7 percent of the total. Also from the above publication, it is calculated that the SO_2 release from burning of utility coal is 24 times higher, on an annual basis, than the SO_2 pollution released by burning of coke-oven gas.

Although on a national basis the amount of SO_2 pollutant released by burning untreated coke-oven gas is a small fraction of the total, it can be expected that desulfurization of coke-oven gas may become a requirement when there is evidence that the SO_2 concentration in the air in the vicinity of steel plants having coke ovens is above some target level. Some steelmakers already strip the hydrogen sulfide from their coke-oven gas, but this practice is far from universal because of the high cost of the present stripping methods.

In anticipation of the future requirement to strip hydrogen sulfide from coke-oven gas, research in progress to develop an effective and low-cost stripping process should be intensified.

New Coking Processes

1. WITH RESPECT TO POTENTIAL FOR CONTROL OF EMISSIONS TO THE AIR, NEW COKING PROCESSES THAT ARE CONTINUOUS ARE SUPERIOR TO THE ESTABLISHED SLOT-OVEN PROCESS. ALSO, IT IS LIKELY THAT A WELL-ENGINEERED CONTINUOUS COKING PROCESS MAY RELEASE LESS POLLUTION THAN SLOT OVENS EVEN AFTER AIR-POLLUTION CONTROLS ON SLOT-OVENS HAVE BEEN DEVELOPED TO THEIR HIGHEST PRACTICAL LEVEL.

From an air-pollution control viewpoint, coking processes that are continuous are superior to the established slot-oven process in potential for control of emissions to the air. It also is judged that with the application of suitably engineered air-pollution control equipment, continuous-coking processes will release less particulate matter than slot ovens even after the air-pollution controls on slot-oven coke plants have been developed to their highest practical level.

The superior amenability of continuous processes to air-pollution control is based on the high degree of containment that is possible within fully enclosed and interconnected equipment, and on the fact that the continuous processes are basically enclosed, rather than outdoor, processes. The emissions problems of the slot-oven coking process are a result of the design and the general operating procedures. The pollution-control advantages of the continuous processes are also a result of the inherent designs.

Continuous coking processes start with pulverized coal that can be fed steadily to charring units or to briquetteing machines without air-pollution problems. In processes where the briquetting is done hot (750 F), the pressing equipment is enclosed so that fumes can be ducted to an effective catalytic combustion unit. Unlike the slot-oven process, the condensible and noncondensible gases are released at a steady rate and composition, and can be piped to the gas-processing and tar-processing sections of the plant without the need for opening of the equipment or for valving from one unit to another. All continuous coking processes cool their product to near ambient temperatures in closed heat exchangers. This eliminates the pollution problems associated with the dumping and quenching of hot product outside.

Like the raw gas from the slot-oven coking process, the gas generated in continuous coking processes is also polluted with organic vapor and particulate matter. Therefore, the final level of emissions to the atmosphere from this source will depend on the effectiveness of the ancillary equipment used to remove the entrained dust and to process the gases for combustion use.

In common with the slot-oven process, the continuous coking processes also pass about half of the sulfur contained in the feed coal to the by-products. Combustion of these by-products will release SO_2 into the atmosphere in about the same amount per ton of coke produced. As a potential disadvantage, the removal of H_2S from the by-product fuel gas in the case of continuous coking processes may be even more expensive than desulfurizing coke-oven gas, because in some instances, the fuel gas from continuous processes has been highly diluted so that there is a higher volume of gas to desulfurize. Research aimed at better methods to strip H_2S from coke-oven gas would also be applicable to any future commercial continuous coking process.

2. FORMCOKE IS A TYPE OF CONTINUOUSLY PRODUCED COKE OF CONSISTENT SHAPE AND SIZE THAT HAS BEEN TESTED ON A LIMITED BASIS IN SEVERAL BLAST FURNACES. THE TESTS INDICATED THAT IT IS FEASIBLE TO USE THIS COKE BUT THEY WERE NOT EXTENSIVE ENOUGH TO INDICATE WHETHER FORMCOKE HAS OPERATING ADVANTAGES OR DISADVANTAGES WHEN COMPARED WITH CONVENTIONAL COKE. AT THE PRESENT TIME, THE VALUE OF FORMCOKE AS A BLAST-FURNACE FUEL REMAINS TO BE DETERMINED.

Limited tests of formcoke in full-scale blast furnaces have indicated that this type of material will withstand the pressures, temperatures, and mechanical abrasion that exist in blast furnaces. The tests with formcoke were not extensive enough, however, to indicate whether formcoke is suitable for use as a complete replacement for conventional slot-oven coke.

The proponents of continuous formcoke processes expect to improve the performance of blast furnaces when formcoke is substituted for conventional coke in a prolonged blast-furnace trial. The improvement is expected to result in higher productivity and lower coke rates in the blast furnace. If it develops that the performance of formcoke in blast furnaces is proved to be both beneficial and significant, this will enhance the position of formcoke processes and stimulate the interest of steel companies in these continuous processes. It is expected that some indication of formcoke's performance in a blast furnace will be obtained when a 10, 000-ton test of formcoke is made for 1 week in a full-scale furnace in Dortmund, Germany. This test is scheduled for January, 1970. If the indications in this trial are favorable, it will be necessary to make longer blast-furnace trials to obtain confirming information and to increase the creditability of the results. The unqualified success of even one type of formcoke in full-scale blast-furnace tests will go far foward gaining steel-industry acceptance of the potential of this type of coke.

Underlying the need for blast-furnace tests on a large scale is the situation that the suitability of a coke for use in a blast furnace cannot be judged in today's state of the art from laboratory or pilot-plant tests alone. Although laboratory and pilot-plant tests are adequate to disqualify cokes that are inferior, these tests are not adequate to quality marginal (or superior) coke.

The product of a continuous coking process need not be a formcoke. The product can also be an unformed lump resembling conventional blast-furnace coke. To date, a product of this type also has not been tested in large-scale blast-furnace use. With regard to eventual acceptance for use in commercial blast furnaces, this lump type of continuously processed coke has the same potential and obstacles as formcoke.

3. ACCEPTANCE OF CONTINUOUS PROCESSES FOR PRODUCING BLAST-FURNACE COKE WILL DEPEND ON THE ATTRACTIVENESS OF THE ESTIMATES BY STEEL COMPANIES OF THE OVERALL COST OF MAKING AND USING THE PRODUCT. AT THE PRESENT TIME, THERE ARE SOME NEGATIVE OPINIONS OF THE ECONOMIC ATTRACTIVENESS OF THE CONTINUOUS PROCESSES THEMSELVES. HOWEVER, ABILITY TO USE A LOW-PRICED COAL AND PROOF OF THE PRODUCT'S GOOD OR EXCELLENT PERFORMANCE IN BLAST FURNACE WOULD ENHANCE STEEL-INDUSTRY ACCEPTANCE OF THIS TYPE OF PROCESS.

If and when some product of a continuous-coking process passes successfully the blast-furnace testing stage, the future of such processes in the United States will then depend on the attractiveness of the estimates by steel companies of the overall cost of making and using the product. Overall cost in this context refers to the cost of making hot metal in the blast furnace, not just the cost of a ton of coke. Promoters of continuous processes and potential users of the product are not yet in agreement on the probability of realizing a lower overall conversion cost (coal to coke) by a continuous coking process. The negative opinions are based on the improved economics of the taller and faster slot-oven designs, and also on judgments that pilot plants are using the continuous coking process have not demonstrated a breakthrough (in terms of increased coking speed) that can be translated into significantly lower capital and labor costs per ton of coke. Although detailed economic evaluation of continuous coking processes is beyond the scope of this study, it is apparent that the economic incentive to build a commercial continuous coking plant will be enhanced (1) if the particular process will accept lower-priced coals than needed for slot ovens, and (2) if the product demonstrates superior performance in blast furnaces when compared with conventional slot-oven coke. Some continuous processes have the potential (or need) for using noncoking coals which can be cheaper than coking coals in some locations. Also, the reserves of first-class coking coals in the United States definitely are limited. Most of the reserves that are well defined already are owned by eventual users. Success of new processes that do not require these coals will expand greatly the nation's reserves of coal that can be used to produce iron and steel.

4. IT IS UNLIKELY THAT ANY FULL-SCALE COMMERCIAL PLANT USING THE CONTINUOUS COKING PROCESS WILL BE OPERATIONAL TO MAKE BLAST-FURNACE COKE IN THE UNITED STATES PRIOR TO 1975.

Considering the present state of the art with respect to continuous coking processes for the manufacture of blast-furnace coke, it is unlikely that any full-scale commercial plant utilizing such a process will be operational in the United States prior to 1975. If all goes well at the early plants, construction of such plants to replace existing coke ovens is not likely to start on a general basis prior to 1980. After this, it will take another 5 to 10 years before a really substantial portion of American blast-furnace coke could be made by a continuous process.

Because of this situation on timing, continuous coking processes cannot be considered to be a potential short-range solution to the immediate problem of lowering emissions from the manufacture of blast-furnace coke. Short-range improvement in air quality will have to come from better control of emissions from existing slot-oven plants.

5. AMONG THE SEVERAL CONTINUOUS COKING PROCESSES STUDIED IN THIS INVESTIGATION, NO ONE SPECIFIC PROCESS OR TYPE OF PROCESS HAS BEEN JUDGED TO HAVE CLEAR-CUT SUPERIORITY OR POTENTIAL OVER THE OTHERS.

Where the objective is to make strong coke with chemical characteristics suitable for use in a blast furnace, the need for a high finishing temperature can be considered established. There are several methods of obtaining the desired coke size. Beyond this, the various processes differ mainly in details of design, selection of equipment, and engineering. The relative suitability of the various schemes to produce an acceptable product at an attractive cost is still to be determined. Some authorities believe that any continuous coking process must be specifically tailored to the coals to be used.

6. IT IS RECOMMENDED THAT FURTHER DEVELOPMENT OF NEW CONTINUOUS COKING PROCESSES BE ENCOURAGED AS A LONG-RANGE SOLUTION TO THE AIR-POLLUTION PROBLEM FROM COKING.

In addition to having potential to lower air pollution drastically, a continuous coking process also has potential for:

(1) Producing blast-furnace coke at lower conversion cost

(2) Decreasing the cost of operating a blast furnace by increasing its productivity

(3) Using coals not now considered usable in slot ovens.

It is recommended that encouragement and assistance be given to demonstration plants specifically aimed at making coke continuously for blast furnaces. This assistance could be centered on the development of air-pollution controls (and targets) for a plant that could be the leadoff for a long-term swing away from the conventional slot-oven process.

It should be noted that although continuous processes have a potential for almost eliminating the emissions from coking, attainment of this potential is not automatic. There will be air-pollution problems to solve, especially on large plants. At the present time, most developers of continuous processes are giving only secondary attention to problems of air-pollution control, and are concentrating their primary effort on the technology involved in making coke.

To a degree, some of the European formcoke pilot plants and demonstration plants are being subsidized by their respective governments. On the basis of information gathered during this study of European processes, it is judged that the time of greatest need for support is in the building of the demonstration plants required to supply small amounts of formcoke or other continuously produced coke for blast-furnace trials. At this critical stage in the evolution of a process, venture capital is not readily available, and the plant is so small that the capital cost per annual ton of product is much higher than that to be expected in a full-scale commercial plant. Further consideration of support in this regard should be somewhat dependent on the results of coming tests of formcoke in blast-furnace trials.

7. IT IS RECOMMENDED THAT RESEARCH BE CONDUCTED TO DEVELOP LABORATORY TESTS SUITABLE FOR PREDICTING HOW A NEW COKE WILL PERFORM IN A BLAST FURNACE AND FOR PREDICTING THE CONDITIONS OF BLAST-FURNACE PRACTICE THAT WILL OPTIMIZE THE PERFORMANCE OF NEW TYPES OF COKE.

If and when some type of continuously produced coke is demonstrated to be suitable for blast-furnace use, the accepted criteria for good blast-furnace coke may have to be rewritten. Some of the questions that will be brought up after the first real success of coke made by a new process will be (1) "What were the characteristics of the successful new coke that were important, and how can these characteristics be further improved?" and (2) "Is other coke made by other new processes the same as the new coke that was successful?"

Until today, laboratory tests on cokes are adequate to eliminate inferior cokes, but do not adequately identify marginal coke and superior coke. Research should be conducted to develop new and improved laboratory tests suitable for predicting how a new coke will perform in a blast furnace. Particular emphasis should, it is believed, be placed on measurements of high-temperature strength and reactivity over a suitable range of temperatures.

It is interesting to note that over the last decade the mean size of slot-oven coke charged to blast furnaces has decreased significantly. Formcokes can be made over a rather wide range of consistent sizes and shapes, but it is to the economic advantage of the formcoke processes to produce small shapes, i. e., smaller than presently used in today's blast furnaces. In this regard, it would be useful to develop data on both small and large pieces of formcoke to determine whether small pieces might be used advantageously in blast furnaces.

8. IT IS RECOMMENDED THAT A TECHNICAL AND ECONOMIC APPRAISAL BE MADE OF THE POSSIBLE FAVORABLE RELATIONSHIPS OF COMBINED FORMCOKE PROCESSES AND CHEMICAL COAL-PROCESSING PROJECTS.

In recent years there has been considerable interest and activity in the field of chemical processing of coal, i. e., the processing of coals to more valuable products. Much of the research in coal liquefaction and hydrogasification is sponsored by the U. S. Government Office of Coal Research. Of the processes about which some of the details are known, char is often a by-product or a residual material. Because most formcoke processes must or can use coal char as a major ingredient, it is considered probable that a formcoke process and a chemical process based on coal could complement each other to their mutual benefit. An independent technical and economic appraisal should be made of the possible favorable relationships that could exist between formcoke processes and processes for hydrogasification and liquefaction of coal.

APPENDIX A

SAMPLE OF EXPLANATORY LETTER SENT PRIOR TO INTERVIEW

A-1

Battelle Memorial Institute · COLUMBUS LABORATORIES

505 KING AVENUE COLUMBUS, OHIO 43201 · AREA CODE 614, TELEPHONE 299-3151 · CABLE ADDRESS: BATMIN

July 24, 1969

Dear Mr.

In a recent telephone conversation, Mr. A. Hoffman of our staff discussed with you our interest in visiting your organization with regard to new developments in the production of metallurgical coke as they relate to improved control of air pollution. As he mentioned in your phone conversation, we are attaching to this letter a brief description of Battelle's research program in this field. The attachment outlines the objectives, scope, and conduct of the current study entitled "New Technological Research on Processes for Making Metallurgical Coke".

After you have examined the attachment, we would like to visit your office and facilities to discuss present and possible future modifications to designs of existing and future slot-type coke ovens for metallurgical (blast-furnace) coke. Information of interest to our study would be generally concerned with (1) the nature of modifications or auxiliary equipment that can be used to lower air pollution during charging, coking, pushing, quenching, and other related operations; (2) the actual or expected effects of design modifications on control of air pollution at coke plants; (3) ease of achieving the required modifications; (4) effect of the design modifications on coke production; and (5) limitations of the modifications. To the degree possible, we would like to obtain drawings and/or photographs of the equipment under discussion.

Although we expect that our discussion with you will involve mostly equipment or modifications for conventional slot-type ovens, we also are greatly interested in considering processes for making metallurgical (blast-furnace)coke by processes other than the conventional slot-type oven (for example, formcoke), and would appreciate any thoughts or experiences pro or con you have along these lines also.

The information and suggestions that we receive from you will be incorporated into a report by Battelle to the National Air Pollution Control Administration (NAPCA). The purpose of the study and the report is to provide guidance to NAPCA in the planning and implementation of future research projects, especially with regard to research that will involve the construction and/or operation of pilot plants, prototypes, and demonstration units.

Battelle staff members who would make the visit are Mr. Tom Barnes and Mr. Al Hoffman. If convenient to you, we suggest the date of August 4, 1969, but we would be glad to have your suggestions if some other time is more convenient for you.

So that our visit can be approved by NAPCA (the sponsoring agency), we request that you reply by letter indicating that the discussions we propose are suitable, and that you expect to disclose to us the kind of information that we are seeking.

If you have any further questions, please contact Al Hoffman at Extension 1339. Battelle's phone number in Columbus, Ohio, is (Area 614) 299-3151.

Very truly yours

H. W. Lownie, Jr.
Project Director

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July, 1969

DESCRIPTION OF BATTELLE MEMORIAL INSTITUTE'S RESEARCH PROJECT ON "NEW TECHNOLOGICAL RESEARCH ON PROCESSES FOR MAKING METALLURGICAL COKE"

NAPCA CONTRACT PH 22-68-65; TASK 10

Recently, Battelle completed the first phase of a research project for the National Air Pollution Control Administration (NAPCA) of the U.S. Department of Health, Education, and Welfare entitled "A Systems Analysis Study of the Integrated Iron and Steel Industry". The reports issued in May, 1969, at the end of the first phase described the present status of air-pollution control technology in the U.S. iron and steel industry, and gave information on the cost of controlling and improving the control of air-polluting emissions. In addition, the Battelle reports identified steel-industry process segments in which air pollution is particularly troublesome. One of the specific recommendations was that NAPCA should undertake new research to make a nonexperimental technological evaluation of systems for achieving improved control of gaseous and particulate emissions from both conventional and "new" processes for making metallurgical (blast-furnace) coke. This recommendation was approved by NAPCA which authorized Battelle to conduct the new research. The following paragraphs set forth the objectives and scope of this new study, describe how the research is being conducted, and how the results will be used.

Objectives

The objectives of this study are:

(1) To expand NAPCA's information and understanding of potential means for controlling air pollution from processes that are being used, or might be used in the future, to manufacture metallurgical coke (for blast furnace use) from coal.

(2) To evaluate the information obtained and to recommend the construction of pilot plants, prototypes, and/or demonstration units where Battelle's conclusions indicate that such experimental work is advisable and justified in the national interest.

Scope

Changes, modifications, innovations, and auxiliaries that have potential for reducing air-pollution emissions from processes for the manufacture of metallurgical (blast-furnace) coke are to be evaluated as described in the following sections.

Improved Systems for Conventional Coke Ovens. New information is to be obtained concerning improved systems for controlling the emission of air pollutants from conventional slot-type coke ovens. The process segments of interest are the pulverizing of coal, transfer operations, charging, coking, pushing, and quenching, as illustrated in Figure 1. Air-pollution problems associated with the transfer of coal to receiving storage, recovery of coal from storage, transfer of coal to the pulverizing plant, the crushing of coke for

from
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subsequent use, and operation of the by-product plant are not included in the scope of this study.

Potentially Controllable New Coking Processes. New information is to be obtained pertaining to potentially controllable new coking processes that eliminate the charging, pushing, and quenching operations associated with conventional slot-type ovens. While new processes are likely to be continuous, no processes will be excluded from consideration solely because they are batch-type processes. However, processes deemed not amenable to the manufacture of blast-furnace coke are excluded.

and the

Potential for Reduction of Air Pollution. An evaluation will be made of the potential for the control of air pollution from coking practice for modified conventional slot-type ovens and for new coking processes. The evaluation will define the direction and magnitude of efforts that will be required (if feasibility is indicated) for applying each of the modifications of the coking process or new coking process to the U.S. integrated iron and steel industry. Recommendations will be made for the application of additional effort and research that should be expended by NAPCA on the behalf of improved control of air-polluting emissions from the integrated iron and steel industry.

Conduct of the Investigation

The information required for this study will be obtained principally by visits of Battelle personnel to the offices, laboratories, and installations of selected U.S., Canadian, and European builders and operators of coke ovens and new coking processes. Some of the visits will be to sites of laboratories or plants. The descriptions and evaluations necessary to attain the objectives of the study will be based primarily on information obtained during the various contacts and visits. However, the evaluation will take into consideration pertinent information published in the technical literature.

Use of the Results

By the end of October, 1969, Battelle expects to prepare and send to NAPCA a draft of a report describing the results of this investigation, including evaluations aimed at preparing recommendations for NAPCA's conduct of or participation in further research involving design, construction, and/or operation of pilot plants, prototypes, or demonstration units for improved control of emissions from processes for the manufacture of blast-furnace coke from coal. The draft of the report will be distributed to and discussed in at least one meeting involving NAPCA, Battelle, and the NAPCA Steel Industry Liaison Committee made up of representatives from eleven of the major integrated U.S. steel companies. After appropriate follow-up activities, Battelle will issue its final report to NAPCA by December 19, 1969.

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APPENDIX B

COKE PLANTS IN THE UNITED STATES

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APPENDIX B

TABLE B-1. COKE PLANTS IN THE UNITED STATES

Location, Ownership	Number and Types of Ovens[a]
ALABAMA	
Alabama Byproducts Corporation, Tarrant Plant	103 Koppers-Becker 100 Koppers 78 Wilputte (tall)
Empire Coke Company, Holt Plant	60 Semet-Solvay (inactive)[b]
Republic Steel Corporation, Gadsden Plant	130 Wilputte
Thomas Plant	65 Koppers
United States Pipe & Foundry Company, Birmingham Plant	120 Semet-Solvay 90 Koppers
United States Steel Corporation, Fairfield Works	272 Koppers-Becker 154 Koppers 63 Otto 146 Koppers-Becker (inactive)[b]
Woodward Iron Company, Woodward Plant	256 Koppers
CALIFORNIA	
Kaiser Steel Corporation, Fontana Plant	315 Koppers-Becker
COLORADO	
C.F. & I. Steel Corporation, Pueblo Plant	60 Koppers (standby)[c] 146 Koppers-Becker
ILLINOIS	
General Motors Corporation, Waukegan Plant	31 Koppers-Becker
Granite City Steel Company, Granite City Plant	137 Koppers-Becker
Interlake Steel Corporation, Chicago Coke Plant	100 Wilputte

TABLE B-1. (Continued)

Location, Ownership	Number and Types of Ovens[a]
International Harvester Corporation Wisconsin Steel Works	45 Wilputte (tall) 67 Wilputte
Republic Steel Corporation, South Chicago Plant	75 Wilputte
INDIANA	
Bethlehem Steel Corporation, Burns Harbor Plant	82 Wilputte (tall)
Citizens' Gas & Coke Utility, Prospect Street Plant (Indianapolis)	41 Koppers-Becker 127 Wilputte
Indiana Gas & Chemical Corporation, Terre Haute Plant	60 Koppers
Iniand Steel Company, Indiana Harbor Works, Plant No. 2	51 Koppers-Becker (tall)[d] 326 Koppers-Becker
Indiana Harbor Works, Plant No. 3	146 Koppers-Becker
United States Steel Corporation, Gary Works	219 Koppers-Becker 140 Koppers 385 Wilputte 85 Koppers-Becker (tall)[d]
Youngstown Sheet and Tube Company, Indiana Harbor Plant	237 Koppers-Becker
KENTUCKY	
Allied Chemical Corporation, Semet-Solvay Division, Ashland Plant	120 Wilputte (inactive)[b] 146 Wilputte
New York Mining & Manufacturing Company, Calvert Plant	200 Beehive[e]
MARYLAND	
Bethlehem Steel Corporation, Sparrows Point Plant	375 Koppers 382 Koppers-Becker
MICHIGAN	
Allied Chemical Corporation, Semet-Solvay Division, Detroit Plant	216 Semet-Solvay 70 Wilputte (tall)

TABLE B-1. (Continued)

Location, Ownership	Number and Types of Ovens[(a)]
Ford Motor Company, Rouge Works	229 Koppers-Becker
National Steel Corporation, Great Lakes Steel Company, Zug Island	146 Semet-Solvay 148 Wilputte
MINNESOTA	
Koppers Company, St. Paul Plant	65 Koppers
United States Steel Corporation, Duluth Works	115 Koppers-Becker
MISSOURI	
Great Lakes Carbon Corporation, St. Louis Plant	18 Koppers 40 Simon-Carves 35 Wilputte
NEW JERSEY	
Koppers Company, Seaboard Plant (Kearny)	65 Koppers-Becker 55 Koppers 55 Koppers (inactive)(b) 5 Koppers (tall)(f)
NEW YORK	
Allied Chemical Corporation, Semet-Solvay Division, Harriet Plant	60 Semet-Solvay 60 Wilputte
Bethlehem Steel Corporation, Lackawanna Plant	171 Koppers-Becker 60 Semet-Solvay 304 Wilputte
Donner-Hanna Coke Corporation, Buffalo (Owned by National & Republic)	100 Koppers (inactive)(b) 136 Koppers
OHIO	
Allied Chemical Corporation, Semet-Solvay Division, Ironton Plant	68 Semet-Solvay 100 Wilputte
Armco Steel Corporation, Hamilton Plant	110 Koppers-Becker
Middletown Plant	76 Wilputte

TABLE B-1. (Continued)

Location, Ownership	Number and Types of Ovens[a]
Detroit Steel Corporation, Portsmouth Plant	70 Koppers 54 Semet-Solvay
Diamond Shamrock Corporation (Pickands-Mather), Painesville Plant	46 Koppers-Becker
Interlake Steel Corporation, Toledo Plant	94 Koppers 57 Wilputte
Republic Steel Corporation, Cleveland Plant	201 Koppers-Becker 153 Koppers
Massillon Plant	31 Koppers
Warren Plant	80 Koppers
Youngstown Plant	162 Koppers 69 Koppers-Becker (inactive)[b]
United States Steel Corporation, Lorain Works	177 Koppers-Becker 59 Wilputte
Youngstown Sheet and Tube Company, Brier Hill Plant	84 Wilputte (inactive)[g]
Campbell Plant	228 Wilputte
PENNSYLVANIA	
Alan Wood Steel Company, Swedeland	110 Koppers 41 Koppers-Becker
Bethlehem Steel Corporation, Bethlehem Plant	186 Koppers 204 Koppers-Becker
Franklin Plant	77 Koppers 151 Wilputte 77 Wilputte (inactive)[b]
Rosedale Plant	88 Semet-Solvay
Bortz Coal Company, Daugherty Plant	70 Beehive[e]
Carpentertown Coal & Coke, Mahoning	264 Beehive[e]
Crucible Steel Company, Midland Division	113 Koppers-Becker 100 Koppers (inactive)[b]
Hillman Coal & Coke, Alicia No. 1 Plant	400 Beehive[e]

TABLE B-1. (Continued)

Location, Ownership	Number and Types of Ovens[a]
Interlake Steel Corporation, Erie Plant	58 Wilputte (inactive)[b]
Jones & Laughlin Steel Corporation, Aliquippa Plant	271 Koppers-Becker 81 Koppers-Becker (inactive)[b]
Pittsburgh Plant	236 Wilputte 79 Koppers-Becker
Menallen Coke Company, Shamrock Plant	108 Beehive[e]
Mt. Sterling Fuel Company, Puritan	12 Beehive[e]
Philadelphia Coke (Division Eastern Associated Coal Corporation)	74 Koppers-Becker
Ruane Coal & Coke Company, Laughead	60 Beehive[e]
Rochester & Pittsburgh Coke Company, Lucerne	262 Beehive[e]
Shenango, Incorporated, Neville Is.	105 Koppers-Becker 35 Koppers-Becker (inactive)[b]
United States Steel Corporation Clairton Works	460 Koppers 409 Koppers-Becker 506 Koppers type[h]
Fairless Works	174 Wilputte
Wheeling-Pittsburgh Steel Corporation, Monessen Plant	93 Koppers-Becker
TENNESSEE	
Woodward Iron Company, Alton Park	24 Semet-Solvay 20 Wilputte
TEXAS	
Armco Steel Corporation, Houston Works	62 Koppers-Becker
Lone Star Steel Company, E. B. Germany Plant	78 Koppers-Becker
UTAH	
United States Steel Corporation, Geneva Works	56 Koppers-Becker (inactive)[b] 252 Koppers-Becker

TABLE B-1. (Continued)

Location, Ownership	Number and Types of Ovens[a]
VIRGINIA	
Christie Coal & Coke Company, Esserville	68 Beehive(e)
Jewell Smokeless Coal Corporation, Vansant	210 Beehive(e)
Norton Coal Company, Norton Plant	90 Beehive(e)
Westmoreland Coal Company, Pine Branch	180 Beehive(e)
Wise Coal & Coke Company, Dorchester	170 Beehive(e)
WEST VIRGINIA	
National Steel Corporation, Weirton Steel Company, Weirton	294 Koppers-Becker
Rock Forge Coal Company, Rock Forge	132 Beehive(e)
Sharon Steel Corporation, Fairmont	60 Koppers
Wheeling-Pittsburgh Steel Corporation, East Steubenville Plant	145 Koppers 169 Koppers-Becker
WISCONSIN	
Milwaukee Solvay Coke Corporation (Pickands Mather), Milwaukee	100 Koppers 100 Semet-Solvay

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(a) Types differ primarily in arrangement of heating flues and checkerwork. Most principal U.S. types of coke ovens are illustrated in Figure 4-4, page 104, of The Making, Shaping, and Treating of Steel, United States Steel Corporation, 8th Edition, 1964.

(b) Inactive status indicates that the ovens are not in use, but if cooled they are believed to have been cooled under careful control, such that brickwork is sound and reactivation is possible.

(c) These ovens are maintained hot and ready to use, but are not in actual operation.

(d) Reported under construction.

(e) Active/inactive status of most beehive coke ovens varies from month to month. Listing offered was valid in 1967.

(f) Test ovens for development of oven design features.

(g) Heated but never put into service.

(h) It is reported that these ovens are of Koppers type as regards flue arrangements, but were actually built by Wilputte.

APPENDIX C

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